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Ann Arbor, Michigan

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**PROCEEDINGS of the ELEVENTH INTERNATIONAL SYMPOSIUM
ON
REMOTE SENSING OF ENVIRONMENT**

25 - 29 April, 1977

CONDUCTED BY

Center for Remote Sensing Information and Analysis
Environmental Research Institute of Michigan

in cooperation with

The University of Michigan
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Environmental Monitoring and Support Laboratory
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WITH CONTRIBUTIONS FROM

Swiss Society of Natural Sciences
Bern, Switzerland

Taiwan Forestry Bureau
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Volume II

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REMOTE SENSING OF AQUATIC PLANTS

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ABSTRACT

To develop a means of rapidly assessing the extent and composition of aquatic plant infestations, a study including both computer simulation and field exercises was begun in 1975 to test various sensors in terms of their ability to detect and discriminate among noxious aquatic macrophytes. A survey of researchers currently studying the problem and a brief summary of their work is included. Results indicated that the sensor types best suited to assessment of the aquatic environment are color, color infrared, and black-and-white infrared film, which furnish consistently high contrasts between aquatic plants and their surroundings.

1. BACKGROUND

One major responsibility of the Corps of Engineers is to maintain the nation's navigable waterways. This maintenance depends partly on the control of noxious aquatic plants that threaten to choke the many channels. The ability to assess rapidly both the areal extent and the species composition of the various aquatic species greatly enhances the control efforts. Decisions concerning the type of control measure to be applied, the magnitude of the application, and the location for application require this information. Currently, an adequate means does not exist at the operational level for rapidly determining the position, extent, and character of aquatic plant infestations over large areas. In addition, the dynamic character of aquatic plant communities requires the ability to examine large areas repetitively, both to identify areas where rapid growth is occurring and to monitor the effectiveness of ongoing control measures.

The U. S. Army Engineer Waterways Experiment Station (WES) research efforts in aquatic plant control include developing an operational capability for mapping the distribution and character of aquatic plants with emphasis on ease of application, rapid execution, and use of available remote sensor systems and technology. The final product of the study will be guidelines for using remote sensors and rapidly extracting and portraying information on aquatic plants.

2. PROBLEM DEFINITION

Personnel of Corps of Engineers districts, divisions, and WES met at the WES in September 1975 to discuss the informational needs of Corps personnel actively engaged in aquatic plant control at the District level. Their needs included knowledge of areal extent and species composition at two scales and frequencies: yearly regional surveys and more frequent detailed surveys. Particular emphasis was placed on the following species: hydrilla (Hydrilla verticillata Royle), Eurasian watermilfoil (Myriophyllum spicatum L.), egeria (Egeria densa Planch.), waterlettuce (Pistia stratiotes L.), waterhyacinth (Eichhornia crassipes (Mart.) Solms.), duckweed (Lemna sp.), water chestnut (Trapa natans L.), and alligatorweed (Alternanthera philoxeroides Griseb.).

Acquisition of the data outlined above requires the ability to: (a) differentiate aquatic plants from their common surroundings, such as water or terrestrial plants, (b) differentiate from one another the various aquatic plant species, and (c) differentiate, for a given species, variations in plant biomass. Obviously, each successive differentiation is more difficult, especially for submersed aquatic plant species. It is also necessary that these

differentiations be made by Corps of Engineers District personnel on a timely basis without additional manpower.

3. SCOPE AND PURPOSE OF STUDY

This paper will present a synopsis of the work that is being accomplished by the Corps Aquatic Plant Control Research Program on the remote sensing of aquatic plants. Work items planned for the future are also discussed.

The initial study efforts have been designed to determine the feasibility of acquiring the desired information for aquatic plants (i.e. location, species, and character) with existing sensor systems that would be available to the Corps districts. The follow-on work will involve formulation of guidelines for applying remote sensors for data acquisition, including setting forth criteria for mission planning, information extraction, and information portrayal.

4. ONGOING INVESTIGATIONS

The work to date has been to determine the feasibility of acquiring information concerning the extent and composition of aquatic plant assemblages by using currently available remote sensing procedures. The following discussion is divided into four sections: a literature review, a description of remote sensing systems, model studies, and field (imagery) investigations.

4.1 LITERATURE REVIEW

A literature review was conducted to identify current relevant work by other investigators. Scientists at the National Aeronautics and Space Administration (NASA) Kennedy Space Center, Florida, under contract to the Florida Department of Natural Resources, have been investigating the use of aerial photography and interactive image processing to monitor the status of hydrilla in small lakes where white amur fish (Ctenopharyngodon idella Val.) have been introduced (Vause and Davis, 1974). Their work has demonstrated the feasibility of accurately delineating and measuring the area of hydrilla infestations with low-altitude aerial photography. Dr. Charles Welby of North Carolina State University at Raleigh used Landsat data in a study for the Corps of Engineers Wilmington District that demonstrated the feasibility of delineating Eurasian watermilfoil infestations in certain North Carolina estuaries (Welby, 1974). Personnel at the Remote Sensing Center, Texas A&M University, College Station, under the sponsorship of NASA, Texas Water Quality Board, and the Corps of Engineers, have examined the use of aerial photography for detecting the presence of submersed and emergent aquatic plant infestations in selected locations in Texas (Benton and Newman, 1976). The results of these latter studies showed the feasibility of using color and color-infrared (IR) aerial photography to detect the presence of species such as hydrilla, waterhyacinth, and duckweed. The results obtained by these investigators are being used to support and guide the ongoing WES effort by providing basic data from which additional experiments are designed and to supplement the results of the WES studies.

4.2 DESCRIPTION OF REMOTE SENSING SYSTEMS

Remote sensing systems vary considerably in the types of information they provide. Airborne photographic sensors operate in the "visible" portion of the electromagnetic spectrum and record the energy reflected from the surface of ground features. The resulting photographs are normally the easiest of all remote sensing products to interpret because the films used have roughly the same sensitivity as the human eye. Thus, the human interpreter is accustomed to what he sees on the photographs. Other sensors, such as the multispectral scanner (MSS) system in Landsat, also record reflected energy and produce photo-like images of the terrain. The major difference is that, in the case of Landsat, the earth's surface is being viewed from space and the resulting resolution is much less than for photos acquired from an aircraft. Landsat provides the advantage of covering large areas in a single scene.

A second type of remote sensing concerns the thermal-IR portion of the electromagnetic spectrum. Thermal-IR systems record the energy radiated from terrain materials. The amount and spectral character of the energy is a function of the temperature and radiation characteristics of the materials. A

third major type of remote sensing concerns radar or microwave systems. These systems (called side-looking radar) transmit a pulse of microwave energy (perpendicular to the airplane's flight path) and record the energy backscattered from the terrain surface. The amount of energy returned is a function of the surface roughness of the terrain surface. Side-looking radar systems also allow coverage of large areas in a short period of time.

Aerial photos and Landsat imagery, because of differences in reflectance characteristics of aquatic plants and their surroundings, are expected to be effective tools for delineating aquatic plant infestations.

Side-looking radar systems may provide a possible tool for regional-type surveys for emergent and floating aquatic plants because of their differences in roughness compared to relatively smooth water surfaces. Thermal-IR sensors are not expected to be very useful. Because of these basic assumptions, aerial photographic, Landsat MSS, and side-looking radar systems are considered to have the most potential for immediate application to the aquatic plant mapping problem, and are, therefore, the remote sensing techniques emphasized in this study.

4.3 MODEL STUDIES

A computerized mathematical model of the relations between photographic remote sensors and the environment has been developed by the WES (Link, 1974) to provide a capability for evaluating the performance of different film-filter combinations for acquiring specific types of data prior to the actual photography. The model was employed to determine the combinations that showed the most potential for allowing discrimination between aquatic plants and their surroundings and between aquatic plant species. The basic process for using the model is as follows: (a) the spectral reflectance characteristics of the feature (a noxious aquatic plant in this case) and its surroundings (other aquatic plants or water, etc.) are input to the program; (b) atmospheric conditions, sensor altitude, and other basic parameters are selected (from a spectrum of conditions available) and the model is run; (c) the output of the computer program is a table giving predicted optical density contrast values for the feature and background and for a variety of selected film-filter combinations. An example of the model output is presented in Figure 1. The right-most column gives the contrast to be expected for the given feature and background for each film-filter combination listed. For single-emulsion films (e.g. film Nos. 2402, 2403, and 2424) the numerical value of the contrast must exceed 0.30 in order for the contrast to be readily detected by the human eye. The model considers each emulsion of multi-emulsion films (e.g. Nos. 2448 and 2443) individually. Therefore, the model output includes a contrast value for the cyan (C), yellow (Y), and magenta (M) emulsions of such films. The optical density values for individual emulsions do not give a true measure of the total contrast that occurs on these films for a feature and background. Thus, some combination of values is necessary. For the purposes of this study, a simple sum of the three (for the three emulsions) predicted optical density values was considered as an approximate value for the total optical density contrast that would occur for the multi-emulsion films. The sum of the predicted contrast values was compared to the 0.30 threshold previously mentioned to assess the capability of multi-emulsion films for discrimination of specific feature-background combinations.

Spectral reflectance curves (for features and backgrounds) are the only input required for execution of the model. For this study spectral reflectance curves of common aquatic plant species and water bodies were obtained in selected locations in New York, Florida, Louisiana, and Texas during the late summer of 1975. Some additional data were obtained in Louisiana, South Carolina, and Mississippi during the summer of 1976. A list of those aquatic plant species and other features associated with them (e.g. water) for which reflectance data have been collected is given in Table I. Species were compared to every other prominent species associated with it, as well as to the surrounding water.

The specific objective of the model studies was to make an initial assessment of the ability of available photographic film-filter combinations for discriminating (a) areas with submersed aquatic plant infestations from areas with no submersed aquatic plants, (b) areas with emergent aquatic plants from surrounding water, (c) specific submersed aquatic plant species from one another, and (d) specific emergent aquatic plant species from one another. It must be recognized at this point that the ability to detect the presence of submersed plant infestations is very dependent on water clarity. It is logical to assume that in very turbid water, it would be difficult to detect the presence of plants only a few centimetres below the water surface; whereas in clear water, it may be possible to detect infestations at much greater depths. The data represent relatively clear water conditions and, as such, should not be assumed to represent turbid water where the adequacy of specific film-filter combinations to detect submersed plants could decrease significantly. Table II presents a comprehensive tabular summary of the results of the model study.

The results of the model studies suggest that in almost all instances (in clear water conditions), it appears feasible to detect the presence of both submersed and emergent aquatic plant infestations with readily available film-filter combinations. In some instances specific comparisons of certain species do not appear to create an optical density contrast of sufficient magnitude to allow discrimination of one species from another. However, there are also instances when available film-filter combinations appear to be quite capable of allowing discrimination among certain aquatic plant species, especially emergent or floating ones.

The ability to discriminate among plant species based on image tone does not necessarily imply the ability to identify a specific plant species without some additional information, such as a prior knowledge of possible species for a given waterbody or growth patterns of a particular plant. Clearly, attributes of plants other than spectral properties must be considered, namely pattern and associative properties. These properties are more difficult to quantify than spectral properties since they are more a subjective impression than an easily measurable entity.

4.4 FIELD STUDIES

To confirm the model predictions and to establish further the capability to acquire information on aquatic plant species extent and composition with aerial photography, a number of field studies were initiated. The field studies consisted of acquiring ground truth data and aerial photographs of selected water bodies having infestations of a variety of aquatic plant species. The field studies were initiated with the acquisition of ground truth and aerial photography at Lake Boeuf, Louisiana, in May 1976; Lake Theriot, Louisiana, in May 1976; and Ross Barnett Reservoir, Mississippi, in April 1976, as shown in Table III. Ground truth data and photographs were obtained at Santee-Cooper Reservoir (Lake Marion), South Carolina, in July 1976. The aerial photographs were obtained from light aircraft with hand-held 35-mm and 70-mm cameras. A second ground truth and air-photo survey was accomplished at Lake Boeuf, Louisiana, Lake Theriot, Louisiana, and Ross Barnett Reservoir, Mississippi, in September 1976 to examine late-season or mature-growth-stage conditions.

In addition to the detailed work conducted at the three test water-bodies, high-altitude (acquired at a scale of 1:120,000 with a U-2 aircraft) aerial photographs and Landsat imagery have also been acquired. These images are being used to determine the relative quantity of information available on high-altitude imagery with respect to the information available on the low-altitude, detailed photos.

Figure 2 shows examples of the low-altitude aerial photographs of Lake Theriot, Louisiana, obtained in the field studies. Features evident on the photos are a canal entering the lake (near the top of each photo), an area of marsh vegetation (upper half of each photo), and an area of water heavily infested with hydrilla with some local infestation of waterhyacinths (lower portion of each photo).

Examination of the photographs in Figure 2 shows that the color-IR film with yellow filter (Figure 2a) produced the best discrimination of the submersed hydrilla from areas with no hydrilla (mainly the canal and its extension into the lake) and the rafts of waterhyacinth. The color film (Figure 2b) shows the rafts and fringe areas of waterhyacinths very well, but does not produce much contrast between the hydrilla-infested areas and the open-water areas, although the hydrilla is detectable. The black-and-white infrared film (Figure 2c) was underexposed but did produce good contrast between the hydrilla-infested areas and open water. The waterhyacinth rafts are detectable on the image but not as well as on the color-IR and color images (Figures 2b and 2c, respectively). The panchromatic film with red filter (2d) shows little contrast between the hydrilla-infested areas and the open-water areas; the areas of waterhyacinth were readily apparent. Of the four film-filter combinations shown, optical densities of (a) 1.04, (b) 0.81, (c) 0.85, and (d) 0.46, respectively, were predicted for hydrilla versus waterhyacinth. These relative values are not inconsistent with subjective evaluation of photographs, except for the relative ranking of the black-and-white infrared (c) and the Plus-X panchromatic film (d). The optical density contrast predicted for each film-filter combination shown for hydrilla and its surrounding water was (a) 0.41, (b) 0.16, (c) 0.68, and (d) 0.05. Again, the relative order of contrast agrees with predictions with respect to the color infrared and color films.

The results of the low-altitude aerial photo examinations are consistent with the results of the model studies and demonstrate the ability of commonly available photographic systems to obtain information concerning the extent and composition of aquatic plant infestations. For example, the results of the model studies summarized in Table II show that each of the organisms for which spectral reflectance characteristics were analyzed could be distinguished from its surrounding water by one or more of the film-filter combinations considered. Field exercises supported this prediction. Similarly, waterhyacinths when photographed with duckweed contrasted markedly in tone, whereas tone discrimination between waterhyacinth and spatterdock was not nearly as distinct. The field results, in summary, essentially agreed with model results in relative intensity of contrast.

Figure 3 shows an enlargement of a portion of color-IR high-altitude aerial photograph of Lake Boeuf, Louisiana. The photograph represents conditions in October 1974, when significant infestations of numerous species (egeria, waterhyacinth, and duckweed) had occurred. The presence of aquatic plants is easily detected on this image. cursory examination of high-altitude aerial photos for Lake Theriot revealed an ability to detect Eurasian watermilfoil infestations, and imagery of Ross Barnett Reservoir showed the ability to detect watershield (Brasenia Schreberi Gmel.) infestations in September 1975.

Figure 4 shows a photographic enlargement of a band-7 (near-IR) Landsat image of the upper portion of Ross Barnett Reservoir in April 1976. Comparison of this image to ground truth data for the same time reveals that areas of watershield appear to be evident on the image. Landsat band-7 imagery of Lake Boeuf, Louisiana, shows obvious evidence of aquatic plant infestations exhibiting many image tones, indicating a possible ability to obtain additional information. Additional work is planned with the Landsat images in digital format to define the information available on Landsat imagery.

5. FUTURE STUDY EFFORTS

Presently, much emphasis is being placed on detailed interpretation and analyses of the different types of imagery acquired from the field studies. A careful comparison will be made among the spectral, spatial, and associative properties of the individual images and the associated ground truth information. The results of this effort will be a definition of the information gathering capability of each sensor type (i.e. to obtain information concerning the composition and extent of aquatic plant infestations) both for detailed and regional scale information.

Side-looking radar will be further investigated as a potential regional survey tool. A radar imaging mission of the Withlacoochee River Basin, Florida and the area from Lake Apopka to Orlando, Florida, has been executed by the 363rd Tactical Reconnaissance Wing, U. S. Air Force Tactical Air Command, Shaw Air Force Base, South Carolina. The side-looking radar imagery was obtained with the AN/APQ 102 synthetic aperture system that covers a ground swath of approximately 32 km for each flight path and has a resolution of approximately 15 m. A previous study conducted for NASA by the Environmental Research Institute of Michigan demonstrated the feasibility of observing large areas of floating aquatic plants using a very sophisticated and experimental radar system. The U. S. Air Force System is a more operations-oriented system in that it has been used for many years as the standard radar imaging system for Air Force reconnaissance missions. High-altitude aerial photographs of the study areas will be obtained to aid in evaluation of the aquatic plant information available on the side-looking radar imagery. Figure 5 shows the enlarged radar image of Lake Tohopekaliga, Florida, with the known aquatic plants labelled by personnel of the Florida Game and Freshwater Fish Commission. Tall plants can be seen quite vividly on the shoreline contrasted against the water surface. Anomalous patterns on the water surface also appear in areas known to be infested with submerged hydrilla and Vallisneria.

The aerial photography obtained for the Santee-Cooper Reservoir System will be used as an example of a large-scale field test for using aerial photos to determine the extent and composition of aquatic plant infestations in a large water body (930 sq km). The photos will be interpreted to delineate areas inhabited by individual (major) plant species and the results field checked for verification. A second aerial-photo mission over the Santee-Cooper complex is scheduled for the spring of 1977.

The follow-on work involves the design, fabrication, and implementation of an effective procedure for Corps district personnel rapidly to acquire needed information concerning the extent and composition of aquatic plant infestations via available remote sensor technology. This may involve development of some automated interpretation procedures for use with high-altitude and satellite imagery for rapid surveillance of very large areas and detection of potential problem areas. In addition, the relative costs of the available procedures and the resources necessary for their implementation will be examined. It is envisioned that several large-scale field programs, such as that described for the Santee-Cooper complex, will be planned and implemented to gain practical insight into effectiveness of the techniques, to identify items requiring additional development, and to effect a technology transfer to potential users.

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TABLE I. AQUATIC PLANTS FROM WHICH SPECTRAL REFLECTANCE DATA WERE COLLECTED

Date	Location	Organism/Feature
Sep 75	Florida	Waterhyacinth, alligatorweed, frogbit, waterfern, tapegrass, pickerelweed, hydrilla, water pennywort, green algae, cattails, water paspalum, Eurasian watermilfoil, salvinia, spatterdock, water lettuce, egeria, associated water
Sep 75	New York	Water chestnut, associated water
Sep 75	Louisiana	Waterhyacinth, coontail, cabomba, hydrilla, associated water
Oct 75	Texas	Waterhyacinth, alligatorweed, associated water
Jul 76	South Carolina	Egeria, waterprimrose, waterlily, associated water
Sep 76	Louisiana	Waterhyacinth (living and dead), American lotus, egeria, frogbit, duckweed, Eurasian watermilfoil, panicum, associated water

TABLE II. TABULAR SUMMARY OF RESULTS OF MODEL STUDIES

	Water	Waterhyacinth	Frogbit	Waterfern	Vallisneria	Hydrilla	Coontail	Egeria	Pickerelweed	Waterlettuce	Salvinia with duckweed	Alligatorweed	Spatterdock	Duckweed	American lotus	Panicum	Naiad	Waterprimrose	Cabomba
Water		□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Waterhyacinth			□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Frogbit				△									□	□	□	□			
Waterfern													△	□	□	□			
Vallisneria													○						
Hydrilla								△	○										
Coontail																			
Egeria																		□	△
Pickerelweed																		□	△
Waterlettuce														○	△				
Salvinia with duckweed														△					
Alligatorweed																			
Spatterdock															□	○	△	□	□
Duckweed															□	○	△	□	□
American lotus																	○		
Panicum																			
Naiad																			
Waterprimrose																		□	
Cabomba																			

Legend

- Discrimination possible with at least one of the film types considered.
- Discrimination not possible
- △- Discrimination marginal
- Blank - Comparison not made

TABLE III. FIELD STUDY SITES

Location	Mean Depth m	Area km ²	Important Aquatic Macrophytes
Lake Boeuf, Louisiana	1-1.5	7.0	Waterhyacinth, <u>Egeria</u> , duckweed, watermeal, American lotus, white waterlily, yellow waterlily, frogbit, <u>Panicum</u>
Lake Theriot, Louisiana	1-1.5	5.2	<u>Hydrilla</u> , waterhyacinth, Eurasian watermilfoil, yellow waterlily
Ross Barnett Reservoir, Mississippi	3.7	121.5	Naiad, pondweed, watershield, American lotus, coontail
Lake Marion, South Carolina	6.7	447.6	<u>Egeria</u> , waterprimrose, naiad

Film	Filter	Optical Density Contrast
2402 Plus-X Panchromatic	12 Yellow	0.017221
2403 Tri-X Panchromatic	12	0.013127
2402	47B Blue	0.178659
2403	47B	0.164144
2402	58 Green	0.079427
2403	58	0.079427
2402	25A Red	0.032514
2403	25A	0.014665
2402	3 Haze	0.063758
2403	3	0.043076
2448C Color*	3	0.000578
2448Y	3	0.270419
2448M	3	0.104692
2443C Color-infrared*	3	0.069592
2443Y	3	0.117260
2443M	3	0.010083
2443C	12	0.146050
2443Y	12	0.067922
2443M	12	0.004641
2424 Black-and-white infrared	12	0.194452
2424	25A	0.202076
2424	87C Infrared	0.173644
2424	87B Infrared	0.213561

Legend

Feature: waterhyacinth, Black Creek, Fla.
Background: spatterdock, Black Creek, Fla.
Atmosphere midlatitude summer haze: 23 km
Zenith angle: 30 deg
Distance to sensor: 1.50 km

* C, Y, and M represent the cyan, yellow, and magenta emulsions, respectively, for multiple-emulsion color and color-infrared film.

FIGURE 1. TYPICAL MODEL OUTPUT

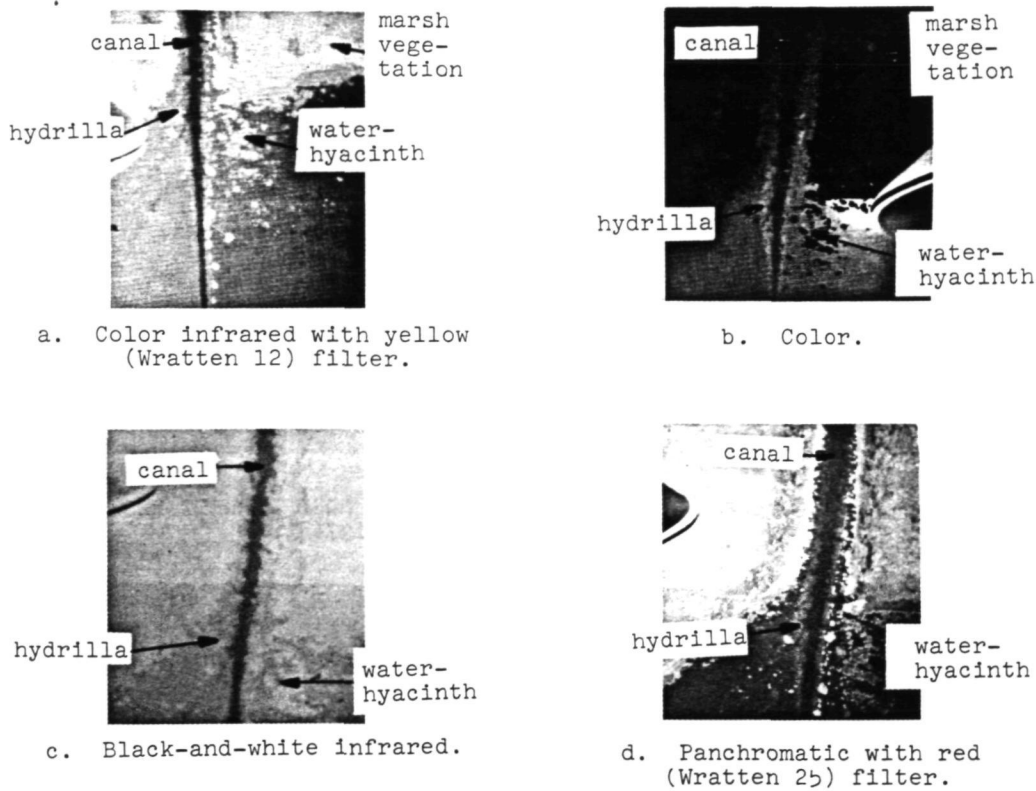


FIGURE 2. LOW-ALTITUDE (c. 300 m) AERIAL PHOTOGRAPHS OF A PORTION OF LAKE THERIOT, LOUISIANA.

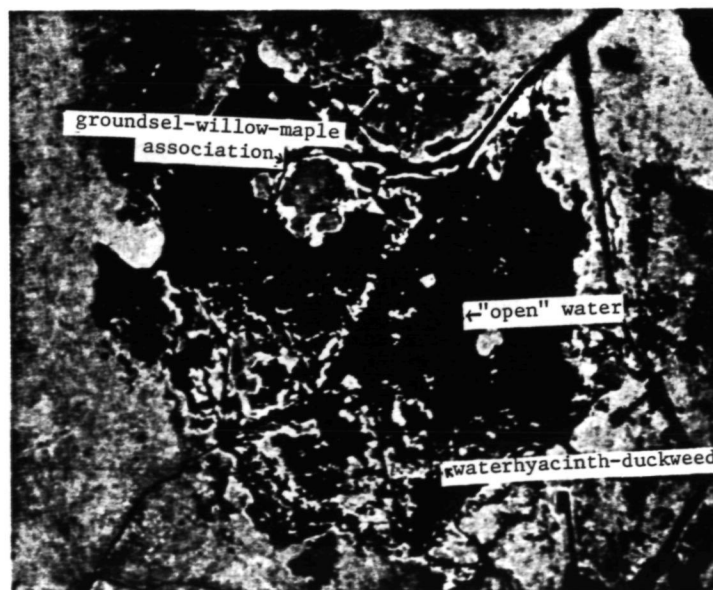


FIGURE 3. COLOR INFRARED HIGH-ALTITUDE (c. 18,000 m) PHOTOGRAPHS OF LAKE BOEUF, LOUISIANA.

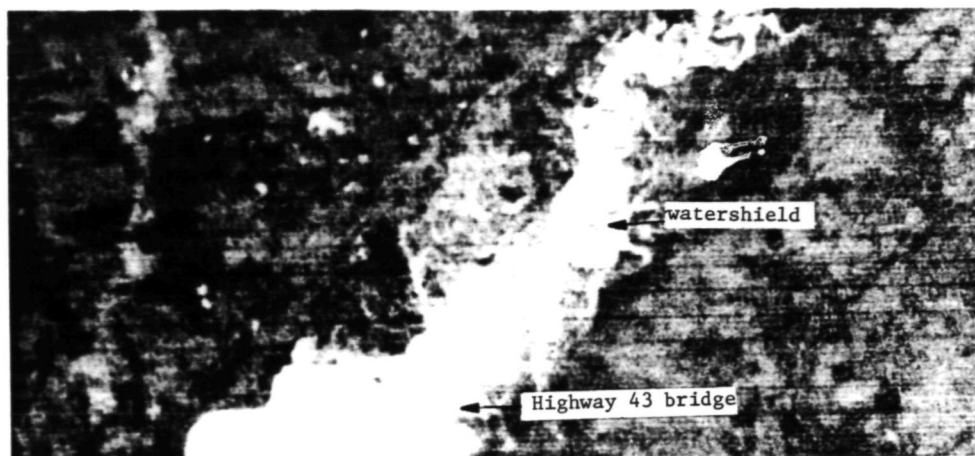


FIGURE 4. PORTION OF LANDSAT BAND-7 IMAGE OF ROSS BARNETT RESERVOIR, MISSISSIPPI (10 APRIL 1976).

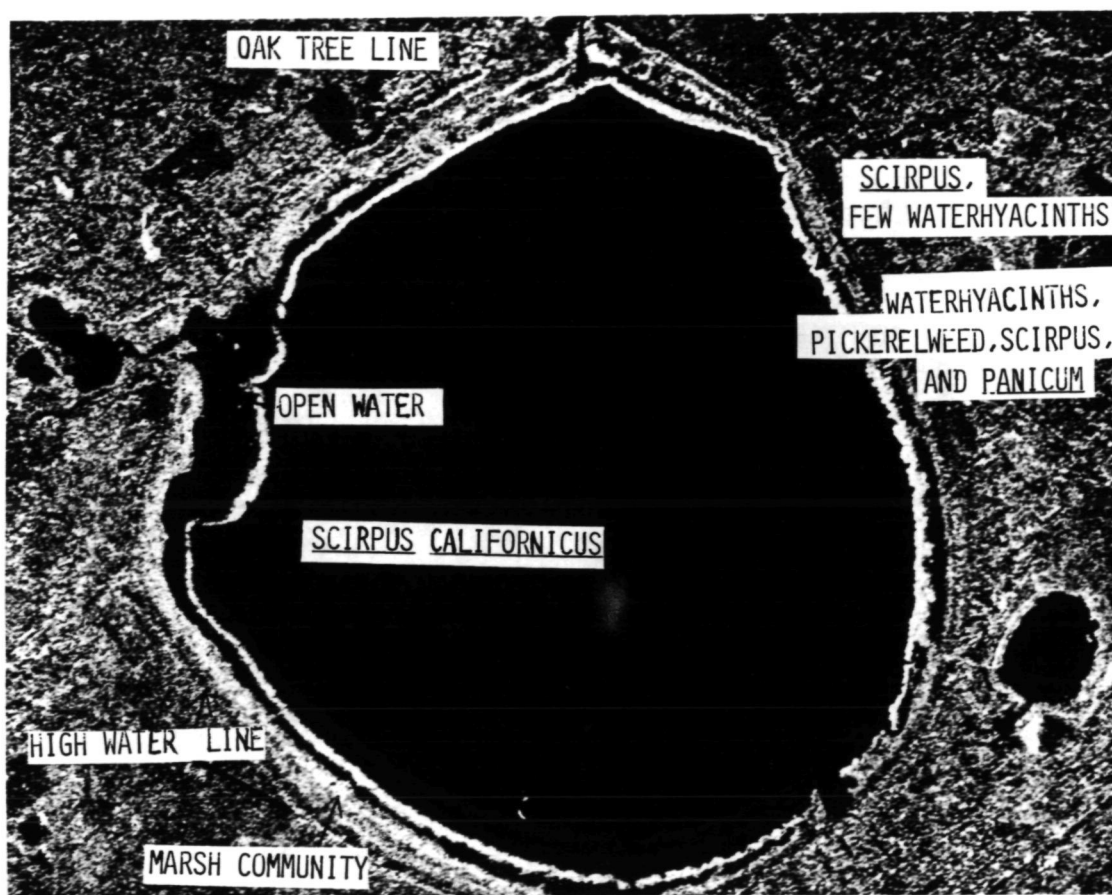


FIGURE 5. RADAR IMAGERY OF LAKE TOHOPEKALIGA, FLORIDA (SEPTEMBER 1976)

PRODUCTION OF A MAP OF LAND-USE IN IOWA
THROUGH MANUAL INTERPRETATION OF LANDSAT IMAGERY

by

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ABSTRACT

The staff of the Iowa Geological Survey Remote Sensing Lab (IGSRSL) recently completed a land-use map of Iowa based on manual photo interpretation of LANDSAT I images. The map, the first of its kind for Iowa, was prepared at a scale of 1:250,000 and printed at a 1:500,000 scale. It displays nine categories of land-use; they are urban residential, urban commercial/industrial, urban open, transportation network, extractive land, agricultural land, forest land, water, and reservoir flood pool. Interpretations were verified through the use of Skylab and high altitude aircraft photography. Information from various maps produced by the U.S. Geological Survey, Iowa Department of Transportation, Federal Aviation Administration, and the Iowa Geological Survey also aided in production of the map. Preliminary copies of the map were reviewed by each of Iowa's 17 Regional Planning Agencies as well as the Iowa Conservation Commission and the Iowa Office of Planning and Programming. These agencies corrected interpretation or handling errors and insured inclusion of major land-use changes that occurred subsequent to LANDSAT image acquisition. A total of 6½ man-months was needed to produce the map at a total cost, from image acquisition through printing, of 18¢ per square mile. The map can provide useful information that may be used in conjunction with other resource data in defining some management goals or policies.

INTRODUCTION

Private citizens, public interest groups, and governmental boards and agencies have expressed an ever increasing desire for information about Iowa's natural resources. In part, this desire has been generated by an increased awareness of the complex nature of the problems relative to management of these resources. Such problems as water pollution, flood protection, highway construction, and shortages of energy and food have recently become increasingly insignificant. The search for the solutions to these problems has lead to the introduction of comprehensive land-use and single resource legislation at both the federal and state governmental levels and to the consideration of more restrictive rules and ordinances at the county and city levels of government.

Land-Use in Iowa, 1976 was produced to provide generalized information on the present utilization of land in Iowa. As the first such map produced in the state, it is intended to provide a synoptic view of the distribution of several categories of land-use within the state.

SOURCES OF DATA

Imagery from the LANDSAT Satellite was the primary source of information used in production of the map *Land-Use in Iowa: 1976*. LANDSAT was chosen because it represented the only available source of imagery that provided statewide coverage which was both current and at a uniform, small scale. These attributes allowed production of an up-to-date map at a workable scale,

1:500,000, using a reasonably small number of images and thus making manual photographic interpretation efficient.

For production of the map nine LANDSAT color infrared composite images were obtained from the EROS Data Center at a scale of 1:250,000 (Figure 1). This working scale allowed direct comparison with the U.S. Geological Survey 1 x 2 degree NK series maps. The complete state coverage of the NK series maps provided a valuable base for the LANDSAT land-use interpretations. Use of this scale for map production allowed a 50% reduction to a scale of 1:500,000 for the completed, printed version of the map. Such reduction enhances the appearance of drafted maps.

Uniformity of information across all designated images and the land-use information desired were the criteria used in choosing the land-use categories to be mapped. The images were acquired with zero or minimal cloud cover between August, 1972 and August, 1973. Where available, summer images were used because they were determined to provide the most satisfactory land-use data.

For the southernmost counties in central and western Iowa suitable LANDSAT imagery was not available. To map land-use in these areas 1:80,000 scale color infrared aircraft photography was used. This photography was obtained by the Iowa Geological Survey in cooperation with the U.S. Soil Conservation Service during the spring of 1975. Other photographic and non-photographic sources of land-use information were utilized to verify LANDSAT interpretations. All of these sources, their uses and references are listed in Table 1.

LAND-USE CATEGORIES

Nine land-use categories were designated to be identified and mapped. They were (1) Urban Residential, (2) Urban Commercial/Industrial, (3) Urban Open, (4) Transportation Network, (5) Extractive Land, (6) Agricultural Land, (7) Forest Land, (8) Water, and (9) Reservoir Flood Pools. With few exceptions the categories chosen were those which were readily identifiable on all the LANDSAT images used. One exception was the location of flood pools associated with Iowa's four major reservoirs. These areas were not identifiable on the imagery because the pools were not full when the images were produced. The maximum pool locations were determined using information supplied by the U.S. Army Corps of Engineers at Rock Island and the U.S.G.S. N.K. series maps.

PRODUCTION OF THE MAP

The actual production of *Land-Use in Iowa, 1976* was accomplished by manual interpretation of the 76cm x 76cm LANDSAT color infrared images followed by repetitively cross-checking interpretations against various other data sources, including data provided by regional planning agencies. Mapping was done in ink on overlays of K & E 44 1035 Stabilene ink-surface film. The first step in this process was to map county lines on the overlay within the limits of the image being interpreted. This was accomplished by locating key roads and intersections near county lines on Iowa Highway Commission *General Highway and Transportation Maps* and on images. Then using these landmarks the county lines were mapped on the overlay. The presence of the county lines assisted photo interpreters in locating particular land-use areas to be verified from other maps.

All federal highways and selected state highways were then added to the overlay. They were located by using the U.S.G.S. 1:250,000 scale NK series maps as a base. These locations were then verified from the LANDSAT images. Where disagreements occurred the LANDSAT locations were used. Normal pool and flood pool levels of Iowa's four major reservoirs were also added to the overlay at this time. Information from both LANDSAT and the NK series maps were used for this purpose.

Interpretation and mapping of the remaining land-use categories (forest, extractive facilities, water, airports, and urban residential, commercial and industrial, and urban open) were then completed from each LANDSAT image.

To facilitate mapping land-use from LANDSAT images, the interpreters began with the areas with which they were somewhat familiar. This allowed each interpreter to gain skill at identifying the spectral reflectance characteristics of

each of the various land-use categories

Features mapped as towns and rivers were verified from the *General Highway and Transportation Maps* and NK series maps, with the latter being used to locate rivers where they become unidentifiable on the images. Airports were checked against the *Sectional Aeronautical Charts* to verify location, runway composition, and size. Features identified as extractive facilities were verified from the *General Highway and Transportation Maps*, NK series maps, and the map of *Mineral Resources of Iowa*. A final in-house check was accomplished by examining all available high altitude and Skylab photography to verify the interpretations from the LANDSAT imagery. Railroads were added later using the *Current Inventory and Transportation Map of Iowa* and the NK series maps for location.

The next step in the production of the map of *Land-Use in Iowa, 1976* was the transfer of interpretations from the overlays to a 1:250,000 scale base. The base consisted of 12 individual maps. Each map included a grouping of counties chosen so the areas of each map were nearly equal and their physical size would allow easy duplication by the Geological Survey's Diazojet Mark III Whiteprinter. The transfer of information to the base maps was done township by township in order to correct for minor variations between the scales of the LANDSAT images and the base maps.

The area of southwest and south central Iowa not covered by good quality LANDSAT color composites was mapped by interpreting land-use information on the 1:30,000 scale, 1975 IGS-SCS color infrared photography. This information was transferred directly from the photography to the ozalid copies of the base maps, using available U.S.G.S. topographic maps for control. The IGS-SCS imagery provided increased resolution and therefore greater land-use information than the LANDSAT imagery. For uniformity, the data was generalized to match the level of detail obtained by LANDSAT interpretation.

After transfer of the information to base maps, black-line ozalid copies of each map were produced, with the various land-uses color coded with Prisma-color pencils. The colored ozalid prints were then regrouped by counties to correspond with the areas included in Iowa's multi-county regional planning agencies, and a copy of the land-use interpretation was mailed to each agency for additions, corrections, and comments. Of the 17 agencies, 14 returned the maps with corrections and suggested changes. Those suggestions consistent with the purpose and limitations of the map were adopted and the appropriate changes were made. The finished maps were then drafted to produce camera-ready copy, i.e. registered overlays from which the printer could directly burn negatives without the costly process of photographically producing color separations. These were then forwarded to the printer for production of the final map.

IDENTIFICATION OF LAND-USE FROM LANDSAT IMAGES

Because none of the eight land-use classifications interpreted from the LANDSAT imagery produced a unique, visual spectral response on the color infrared composites, a number of factors had to be considered in identifying the land-use of any given area. Some of the factors considered were color (hue and saturation), shape, size, and association with other features. The following section describes many of the parameters used to identify each land use as well as some of the possible problems in interpretation associated with each.

1. Urban Residential. Three classes of urban land-use are differentiated on the map of *Land-Use in Iowa: 1976*. These are residential, commercial/industrial, and open land. On the LANDSAT color infrared images developed, urban areas appear in flesh-colored tones, with white and/or soft blue mottling present in larger cities. Their identification is often aided by their location at the hub of a radiating road network.

Urban residential areas dominated by single family dwellings produce a flesh to pink coloration on the LANDSAT imagery, resulting from the integration of white tones produced by such high reflectance objects as houses, roads and driveways, and red tones produced by the high reflectance of infrared EMR by

trees, lawns and other vegetation. The classification of a particular reflectance as a residential area is a generalization because such areas may contain small businesses and even light industry. However, they are predominantly residential.

The August imagery has proved to be the best for differentiating urban residential areas. They can be easily mapped at this time of year due to their contrast with the more uniformly red colors produced by surrounding croplands and other heavily vegetated areas. Much of the urban vegetation is stressed by lack of moisture, mowing and other urban influences. This stress combined with the integration of white light from the previously mentioned highly reflective objects reduces the intensity of the red tones of urban vegetation as compared to most rural vegetation. The only features which may be confused with urban areas at this time are large areas of sparsely vegetated, well-drained (usually sandy) soils. Such areas are generally found only near major rivers.

Identifying urban areas on the May and June images has proven to be more difficult. At this time the vegetation within urban areas is especially vigorous, reflecting highly in the near infrared. This produces a bright red and white mottled appearance on the LANDSAT prints which is very similar to the response produced by the combination of forestlands, grasslands, and well-trained soils often found in drainages near urban areas.

Low density urban residential areas may be erroneously omitted from this classification. This omission is the result of large green spaces and associated high reflectance of EMR in the infrared wavelengths. Such areas can be easily misidentified as forest or urban open.

2. Urban Commercial and Industrial. Once an urban area has been identified commercial and industrial areas can be differentiated based on their responses on the color infrared print. Two types of responses are common. Older commercial or industrial areas appear as bluish colors often ringed by a white aureole. The blue colorations are produced by the limited reflectance from the asphalt roofs of older buildings, with the tone of blue dependent upon the amount of white contributed by high reflectance features such as streets, parking lots, etc. between the buildings. The more white present, the lighter the blue tones. The white aureole is produced by the high reflectance features surrounding the complexes.

Newer industrial complexes and commercial facilities commonly use more modern roofing practices and are almost always associated with large parking lots. These produce a bright white response within the urban areas on the LANDSAT prints due to their high levels of non-selective reflection of incident EMR.

These high reflectance industrial and commercial areas may be confused with other large features with similar high reflectance characteristics. Such land-uses as sand and gravel pits, quarries, and certain large, well-drained, bare soil areas as well as such urban features as high density residential areas, large apartment complexes, and institutions may be misinterpreted as commercial and industrial. Other industrial or commercial facilities of smaller size, dispersed among other land-uses or well landscaped with vegetation, may be misidentified as urban residential.

3. Urban Open. The final urban classification, urban open, includes extensively vegetated areas, such as parks, within urban areas. The more natural settings of these parklands tend to promote healthier vegetation than is found in other urban situations. Some reduction of urban stress and much less highly reflective material create a brighter red response, similar to that produced by non-urban vegetation. There is little chance of confusing this land-use with others. In some cases, however, low density, heavily-wooded residential land may be confused with urban open. Agricultural land surrounded by urban areas could also be confused with urban open land use, but these are rare situations.

4. Transportation Network. Three major transportation systems were included on the land-use map: highways, railroads, and airports. All three are represented on the map by only a selected portion of the facilities actually present.

All federal highways and selected state highways were mapped. Although the transportation network in Iowa represents a significant land-use in Iowa (over 3% of Iowa land is utilized as roads or rights of way)¹, only a portion was included on this small scale map, primarily as an aid in the location of specific areas on the map. The decision to map all federal highways, and only key state highways in areas not served by the federal roads, allows a relatively uniform distribution of roads across the state without de-emphasizing other land-uses.

Identifying selected highways can be difficult. The August images proved optimal in identification of the road network in Iowa. The responses produced on August LANDSAT images by this network were off-white to yellow linear features. The large number of section line roads in Iowa create a striking, square, grid-like geometric pattern over the majority of the state. Only in the high relief areas of southern and northeastern Iowa is this grid absent. Because of this large network of roads, and the difficulty in differentiating between concrete, asphalt, and gravelled roads it was necessary to work closely with the U.S.G.S. 1:250,000 scale maps, state highway maps and regional planning agencies in order to assure that the proper roads were mapped. The road network is much less distinct on the spring images. However, at this time paved roads display a slightly greater reflectance than the gravel roads. Even so, it was necessary to use supplementary highway maps when interpreting spring imagery.

At the request of many of the state's Regional Planning Commissions, principal railroad routes as chosen by the Iowa Department of Transportation were also included. Although the actual railroad right-of-ways can only rarely be seen on the LANDSAT images, their diagonal trend breaks up the rectangular pattern of agricultural land. This effect leads to relative ease in mapping railroads in the state. The U.S.G.S. 1:250,000 scale maps were used to aid in locating the railroads where the routes were not identifiable on the imagery.

Paved airport runways were readily identifiable on all LANDSAT imagery used for this project. They, like the roads, are excellent reflectors of visible and near infrared EMR and therefore, have an off-white appearance on the imagery. They are relatively short in length and often oriented in a north-westerly or northeasterly direction. Because of the relative abundance of aircraft landing strips around the state, both public and private, it was decided to include only public airports with hard-surfaced runways of at least 457.2 meters in length. This decision allowed use of Federal Aviation Administration Sectional Aeronautical Charts to confirm the locations of airport as interpreted from the imagery.

5. Extractive Land. Extractive facilities, including quarries, sand and gravel pits, and recent borrow pits, are characterized by a high reflectance of incident electromagnetic radiation. On the LANDSAT images these facilities have a very bright white response because of the highly reflective and non-selective nature of the interaction of such materials with EMR. Once the interpreter becomes familiar with this response, they can usually be differentiated from other land-uses. There are, however, other responses which may be confused with these extractive facilities. Very dry, and well-drained soils which have not been recently disturbed often produce a similar white response on the imagery. Urban commercial and industrial areas with newer buildings and large parking lots also produce this white response as do new housing developments and trailer courts. Generally the white produced on the image is seldom as intense as that produced by an extractive facility.

Perhaps the land-use most easily confused with extractive land is large cattle feed lots. The many buildings, use of concrete surfaces, and compaction of bare soil by the cattle create a high reflectance situation very similar to an extractive facility.

Several features of extractive land aid in its identification. Sand and gravel pits are commonly found in association with streams. High reflectance in such locations, especially when vegetation is vigorous, may be mapped as extractive land with a high degree of certainty. Recent borrow pits, areas where materials have been removed for construction, are most frequently found along major highways, particularly interstate highways. Thus high reflectance

areas directly associated with such highways, and not associated with urban areas, have a high probability of being borrow pits. In identifying quarries, the presence of a flooded portion and its associated blue (highly turbid) water reflectance may provide a helpful clue.

Coal strip mines, also mapped as extractive, have a much different response. On the LANDSAT images they have a grayish-blue coloration very similar to the older commercial and industrial areas discussed. The tones of the strip-mined areas range from almost black to light blue and often display a white aureole. The grayish-blue tones are produced by the black shale and other rock materials which are devoid of vegetation. Strip mines are very easily confused with bare, poorly drained soils. Thus they are often impossible to identify on spring or fall imagery where bare fields are common. On the August imagery, however, the strip-mined areas may be easily spotted and identified because of the high contrast between the vegetated fields and unvegetated mining areas.

6. Agricultural Land. The vast majority of the area mapped as agricultural land is utilized in agricultural related endeavors, such as row crops, cover crops, pasture land, and farmsteads. Many other land uses, however, also exist in these areas. These include such uses as non-pasture grasslands, scrub land, roads and right-of-ways, very small or low density residential areas, and small ponds and wooded areas. The failure to display these land-uses is not an attempt to minimize their importance. They have not been differentiated on the map because of the inability to accurately interpret them with uniform accuracy over all of the LANDSAT images studied, and the difficulty in displaying them on the small-scale final map.

Row crops, primarily corn and soybeans, are planted in the spring, usually in middle and late May, respectively, and cover over 70%² of Iowa's agricultural land. Areas devoted to row crops can be identified on the May and June images as colors of dark to light grayish blue-green. These areas are bare ground, plowed either in the spring or the previous fall. The more recently plowed fields usually appear darker than those plowed earlier because of greater surface roughness and greater surface soil moisture. Rough ground scatters sunlight, reflecting a lower percentage back to the detectors on the LANDSAT. Rain, wind, and other erosive forces act to smooth these fields with time, increasing their reflectance and changing their appearance on the color infrared composite to lighter tones of grayish blue-green. The amount of soil moisture present also affects the tones of bare soil areas. Water, whether as standing water or soil moisture, absorbs a very large percentage of the incident infrared EMR. This makes poorly drained areas with higher soil moisture appear as darker tones. Conversely, better drained areas have lower soil moisture and reflect a greater percentage of incident EMR to the satellite. This produces lighter tones on the images.

The grayish blue-green color is attributable to the general brown to black color of Iowa soils. Brown is produced by combining reflection of EMR of red light wave-lengths with a lesser amount of green wavelengths. When the green reflectance is colored blue and the red is colored green as they are in producing color infrared images, blue to green-blue color is produced. The intensity of the reflectance of these colors and the amount of infrared light reflected controls the tone of the response.

On the July image those row crops planted early in the growing season have germinated and grown to the extent that they can no longer be differentiated from cover crops by a human interpreter. This is also true in August although the Purdue University Laboratory for Application of Remote Sensing has successfully used computer analysis to differentiate corn, beans, and other crops using early August LANDSAT imagery.³ Such computer manipulation of imagery requires sophisticated equipment and technology and was not considered necessary for a general land-use analysis.

Cover crops, primarily winter wheat, oats and hay crops, constitute about 10.5%⁴ of Iowa's agriculture land. Winter wheat is planted in the fall and is not easily differentiated from hay crops, pastures, and non-pasture grasses on spring imagery.

Some differentiation of these agricultural land-uses is possible under ideal conditions. For example, heavily grazed pastureland can sometimes be identified, especially in times of drought, by the lower infrared reflectance of the grazing-stressed grasses. Similarly, for a few weeks subsequent to mowing, hay crops can be differentiated by their lower infrared reflectances. Both of these conditions occur at random times, therefore, no single image is adequate for mapping either land-use without serious omission errors.

7. Forest Lands. The classification of forest land includes all identifiable wooded areas except those within urban areas or reservoir flood pools. Generally wooded areas of 10 acres or larger could be identified; however, this varied with forest location, season, and image quality. Forested areas, like other concentrations of vegetation, reflect very highly in the infrared portion of the electromagnetic spectrum giving them a red appearance on the LANDSAT color infrared composite images. The red of these forests is a darker red than that produced by crops, pasture or non-pasture grasslands. In some instances, however, particularly on the springtime images, patches of forested land can easily be confused with individual vegetated fields. Also, the ability to differentiate between forest and non-forest vegetation is reduced as image quality deteriorates towards the edges of some images. Midsummer and snow-covered winter scenes provide the best definition of these forested areas.

In Iowa the location and shape of many forested areas assist in their interpretation. They usually occur as irregularly shaped patches and frequently border drainage-ways. However, many of the thin gallery forests along drainages were not mapped because of difficulties in identifying or mapping them at the small map scale used.

8. Water. Reservoirs, lakes, ponds, and rivers have been classified as water on the land-use map. Iowa has four major reservoirs: Coralville, Rathbun, Red Rock, and Saylorville. The areas of these reservoirs mapped as water are the recreational pool level of each as determined from information obtained in part from the Corps of Engineers and the 1:250,000 NK series maps. It was necessary to use this supplemental data because on the August 1972 image of southeastern Iowa, both the Coralville and Rathbun Reservoirs are at abnormally high levels, as is the Red Rock Reservoir on the May 1973 image of central Iowa. The new Saylorville Reservoir was not yet filled when the map was published but was also mapped at its designed recreational pool level.

All lakes and larger ponds which could be identified on the LANDSAT images have been mapped. The minimum resolvable size varies from image to image depending on season and pond location. Five acre and larger ponds can be identified on the August imagery, but few ponds or lakes smaller than 50 acres can be identified on the May and June images.

This inability to distinguish water in the spring-time images is primarily due to the similar responses of water and moist, bare soil. Clear water absorbs a very large percentage of the incident near infrared EMR. This, combined with water's low reflectance of red and green EMR, creates a black response on infrared images. The response goes from black to blue with increased turbidity. Bare soil, especially if it is moist or freshly plowed, also produces a black to dark blue response. Therefore, smaller water bodies surrounded by moist, bare soils are difficult to identify because of the reduced contrast. However, smaller water bodies surrounded by materials with a higher reflectance can often be mapped because of increased contrast. Such situations occur where lakes are ringed with trees or grass or, in the case of quarries or gravel pits, where rock is exposed surrounding the open water.

Rivers were also often difficult to identify. Where there is no significant vegetative border in springtime images, the rivers are often not differentiable from bare soils. On the August images the canopy effect of trees growing along narrower rivers often obscures them. Because of these problems, locations of some sections of the rivers mapped on the land-use map were obtained from the U.S.G.S. 1:250,000 scale maps. All information derived in this manner was overlain on the images to correlate locations as closely as possible. Because of these interpretation difficulties it was arbitrarily decided to map

all streams identified as rivers on the U.S.G.S. maps and to exclude creeks irregardless of their discharge.

9. Reservoir Flood Pools. Reservoir flood pools are those areas of land inundated when a reservoir is at maximum capacity.

The land included in these flood pools is owned by the Federal Government and controlled by the Corps of Engineers. It is intermittently flooded, sometimes for prolonged periods, but some areas are leased to farmers for raising crops when possible. These flood pool areas may also contain forests and are frequently used as recreation areas during times of lower water levels. However, since the flood pool represents the restricting factor in determining land-use in these areas, other possible uses have not been mapped. The boundaries of all four reservoir flood pools displayed on the map were determined from information provided by the Corps of Engineers and U.S.G.S. 1:250,000 NK series maps. This was necessary because none of the reservoirs were at their maximum pool levels when imaged by LANDSAT.

MAP LIMITATIONS

Even though many techniques were employed to reduce errors during the production of the map *Land-Use in Iowa: 1976* undoubtedly some mistakes or misinterpretations are present. However, the use of many sources of data to verify LANDSAT interpretation and the final inspection by the state's regional planning agencies has minimized these errors. Most of the possibilities for error or misinterpretation have been discussed in detail throughout this text. Some registration problems in printing have shifted geographic locations slightly on portions of the map, and a few outlined land-uses were left uncolored due to printer error. The lack of an accurate base of comparison hinders the determination of map accuracy.

To date only a minimal number of errors have been identified on the map. The staff of the Iowa Geological Survey Remote Sensing Laboratory feel that, as a regional interpretation, the map of *Land-Use in Iowa: 1976* represents an accurate portrayal of the utilization of land in Iowa.

CONCLUSION

The Land-Use Analysis Laboratory at Iowa State University in Ames, Iowa, has digitized the map of *Land-Use in Iowa: 1976* and subsequently analyzed the map to determine the area consumed by each land-use category and the percent of the total area of the state represented by each. The following are the results of their study.

Land-Use	Area Hectares x 1000	Square Kilometers	Percent of Total State
Urban Residential	157.1	1,570	1.1
Urban Commercial/Industrial	28.6	285	0.2
Urban Open	14.3	143	0.1
Transportation Network*	14.3	143	0.1
Extractive Land	14.3	143	0.1
Agricultural Land	12,999.7	129,997	91.0
Forest Land	914.2	9,413	6.4
Water**	128.6	1,285	0.9
Reservoir Flood Pool	42.9	427	0.3
Total State	14,314.0	143,136	100.2%

* Transportation Network figures include airports only

** Inland rivers are not included in Water figures.

Because of the difficulty in clearly portraying thin, linear features such as railroads, highways, and most rivers to scale on a small scale map such as the map of *Land-Use in Iowa: 1976* and the inaccuracies involved in digitizing such features, they were not included in the Land-Use Analysis Laboratory's area percentages. Information on the land area used by these features can be obtained from the Iowa Department of Transportation⁵ and Iowa Conservation Commission.⁶

Land-Use in Iowa: 1976 was produced in a relatively short time and at a low cost. Map interpretation time, including actual interpretation and checking with other available imagery and maps, averaged about 5 man-days per area for each of the 12 multi-county groupings used for the map production. Another 2½ man-day per area was needed for transferring, corrections, and other changes; this totaled about 90 man-days of interpretation. The nine 76cm x 76cm enlargements of LANDSAT images used were obtained at a cost of \$40.00 each from the EROS Data Center, and one roll of mylar and ozalid paper was used. The combined cost for producing the photointerpreted map was \$4910.

An estimated 40 man-days was needed by the drafting department to produce camera-ready copies of each of the 12 area maps. Six rolls of mylar were used in the final drafting, and including the drafting pen points consumed, the total drafting costs were \$1870.

The cost to print 2700 copies of *Land-Use in Iowa: 1976* totaled \$3398. The total cost of production of the map was \$10,178.

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FIGURE 1. LOCATIONS AND DATES OF LANDSAT COLOR COMPOSITES USED FOR MAPPING.

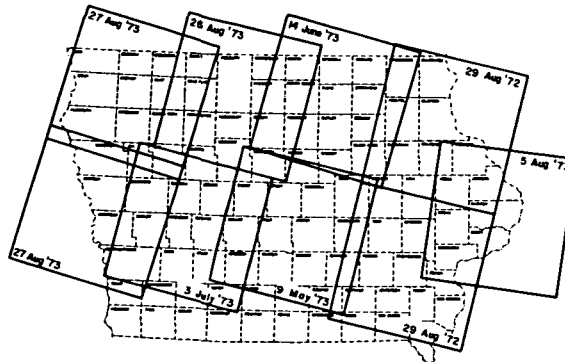


TABLE 1. DATA SOURCES USED FOR LAND-USE MAP PRODUCTION.

DATA	USE	SOURCE
<u>Photography</u>		
Landsat 76cm x 76cm color enlargements (1972-75) Scale: 1:250,000	general land-use mapping	EROS Data Center Sioux Falls, S.D.
NASA Skylab Photography (1973-74) Scales: 1:2,800,000 and 1:950,000	used to check LANDSAT interpretations	EROS Data Center Sioux Falls, S.D.
IGS-SCS High Altitude Southern Iowa River (1975) Basin Study Photography Scale: 1:80,000	mapping regions of Southern Iowa not mapped from LANDSAT-- also used to verify LANDSAT interpretations	Iowa Geological Survey Remote Sensing Lab Iowa City, Iowa
NASA Cornblight Photography Scale: 1:120,000 (1972)	used to check LANDSAT interpretations	EROS Data Center Sioux Falls, S.D.
NASA High Altitude Des Moines (1973) to Omaha Flight Scale: 1:120,000	used to check LANDSAT interpretations	EROS Data Center Sioux Falls, S.D.
<u>Non-Photographic Data</u>		
U.S.G.S. 1:250,000 scale N.K. Series Maps; NK 14-3 15-6, 14-9, and NK 15-1 through 15-12	used to prepare county outlines on base map; verify city, highway, river, railroad, and reservoir location	U.S. Geological Survey Iowa City, Iowa
1975 Official Highway Map of Iowa Scale: 1:625,000	used to verify city location and size and highway location	Iowa Department of Transportation Ames, Iowa
Current Inventory & Transportation Map of Iowa (1974) Scale: 1:1,580,000	used to identify and locate principal railroads & airports	Iowa Department of Transportation Ames, Iowa
Sectional Aeronautical Charts, Omaha and Chicago Scale: 1:500,000	used to locate and identify principal airports	Federal Aviation Administration Local Airports
Iowa Highway Commission County Highway & Transportation Maps, Scale: 1:250,000	used to locate and identify towns, roads, & extractive facilities	Iowa Department of Transportation Ames, Iowa
Mineral Resources of Iowa Scale: 1:500,000	used to check extractive facilities	Iowa Geological Survey Iowa City, Iowa

THE APPLICATION OF IR- AND
MSS-DATA IN THE RUHR DISTRICT, GERMANY

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ABSTRACT

The Siedlungsverband Ruhrkohlenbezirk (Ruhr Planning Authority - SVR) is a user of remote-sensing data, which are needed for its planning decisions. Since its foundation it has appreciated the value of aerial photography: IR and MS scanners have been in use since 1970. The IR data provide information about the thermal loading of the Rhine, and are also particularly useful for determining the climatology of the urban and surrounding country areas. The methods used by SVR to interpret the IR pictures are described. The object of this work is the production of maps indicating the thermal distribution in the conurbation.

INTRODUCTION

The Ruhr District is a polycentric agglomeration with 5.68 million inhabitants. It is well-known as the most important industrial region in Germany. This region also has the most difficult environmental problems. The Siedlungsverband Ruhrkohlenbezirk, SVR, is a communal umbrella organization whose job it is to take note of, and solve, problems of the utilization of waste-products, leisure, traffic, landscape planning and the safeguarding of green areas throughout the Ruhr District. As early as 1926 the aerial photograph was introduced as a basic material. Since this time picture-taking flights have been carried out in regular intervals of a few years. Pictorial plans on a scale of 1 : 5000 are then produced from this material and placed at the disposal of the municipalities as a basis for planning. Since 1973 a mapping of actual utilization has been carried out with the aid of this pictorial material. It was begun on a scale of 1 : 25000 and is now being continued on a scale of 1 : 10000. This work produces important information about area balances. Now is the time, however, to speak in more detail about the employment of IR- and MS-Scanners. These instruments were introduced in the Ruhr District as early as 1970 and have proved themselves especially in water-supervision. An even more important development in the use of scanners was in the scope of the cities, as the IRLS-data produce important information about the "heat-island" of the city, the activity of green areas and the distribution of land-utilization.

Since 1972 the Rhine has been flown over 18 times in sections. In 1973 the entire Ruhr District was photographed 4 times with a scanner, as were a further 8 test areas. In the autumn of 1974, together with the entire Ruhr District, a test area was photographed from various altitudes. In 1975 4 flights in the course of a day produced the thermal behaviour of the earth's surface in the height of summer. As in 1974, an 11-channel scanner was also employed.

The flights over the Rhine between Krefeld and Wesel show clearly the behaviour of warm cooling-water inlets along the river. Their total number is 21. in accordance with the quantity and temperature of the water brought in, cooling-water banners of varying lengths are shown:

3 banners are longer than 5 km, 5 banners are up to 4 km long, 4 banners have a length of about 1 km and 9 of the banners are only a few metres long.

The "heat-island" of the city is especially easy to recognise in the IRLS-photographs. The example of the city of Dortmund can be used to show how the surface-temperature rises with increasing housebuilding.

The individual areas of the city have a varying thermal behaviour in the course of a day. As has been shown in an examination of the city of Essen, above all the degree of sealing can be correlated with the overheating of the city.

Relief plays a large role in a city's climate. The interpretation of IR-photographs must, however, give separate consideration to this, as the work for the city of Wuppertal shows.

The Ruhr District is a polycentric agglomeration whose settlement structures are very complex. Important findings concerning the area-pattern of the settlements and the thermal burden on the area can be deduced from the heat-pictures.

A scanning of the data also gives us here the possibility of making quantitative statements about area-sizes and area-behaviour.

Apart from the evaluations of thermal pictures, however, the automatic evaluation of MSS-data is becoming ever more important for mappings of area utilization. It is above all in the inner-city area that there are still difficulties. Preliminary results concerning the distribution of green areas in the city are, however, promising.

SURVEY TECHNIQUES

The SVR has used the Type DS-1230 Daedalus Scanner for IR and MSS flights since 1973. The data recorded on magnetic tape are reproduced on to 12cm film by a DEI 610 Processor. The individual channel data can be reproduced individually or in combination either analogue or by the equi-density technique. SVR processes and interprets the scanner data under contract to the District Councils in the Association Area, and the results must therefore be reproduced in map form for the various planning officials in the towns to use as basic working material. Because geometric rectification of the

scanner data is still very expensive, and also as the problem of correcting the radiometric errors is not solved, cartographic conversion of the scanner interpretations still presents great problems. However, one compensation is that aircraft height and time of photography are not so critical.

There are, however, considerations concerning the most favourable time for flying (Lorenz, 1973), and the most suitable weather conditions, but these are so rare in the Ruhr area that flying should take place, ideally without delay, during any relatively dry period when the sky however, can be predetermined, depending on the object of the particular task.

Tasks encompassing the whole Ruhr area are flown at 4,500m. It was found that the most suitable height for town analyses was about 2,000m above ground level, while detailed tasks were flown at between 400 and 800m.

As an example, SVR has had produced a map of the surface radiation temperatures of the whole Ruhr area, for which the colour equidensities to a scale of 1 : 110,000, had to be converted manually into a 1 : 50,000 scale chart representing the core zone of the Ruhr area. The area extends some 60km East-West and 30km North-South. The flight pattern flown during the night of 25 April, 1973 consisted of 6 parallel East-West tracks. The Digicolor process covers the temperature range from -3°C to $+9^{\circ}\text{C}$ in 2°C steps.

SURFACE TEMPERATURE BEHAVIOUR

a) Homogeneous Surfaces: The thermal behaviour of homogeneous surfaces is best determined by radiometer, a device which measures the heat radiation from a surface. As the scanning angle of the device is very small (1°), the measurement taken is very nearly a point reading.

Comparisons of the surface temperatures of varying types of surface and surface-coverage have been made by a large number of authors (viz, inter alia, ALBRECHT, 1952, LORENZ, 1962, 1966, 1967, LENSCHOW and DUTTON, 1964, FUCHS and others, 1967, FUJITA and others, 1968, KESSLER, 1971, GAY, 1972, and von HOYNINGEN-HUENNE, 1973). Most of these measurements concentrated on the mid-day maximum, and some on the early morning minimum, in all cases under cloudless sky conditions. Fezer, 1975, has collated the investigation results of the above authors. The resultant daytime surface-temperature variation curves are shown in Fig. 1. Kessler, 1971, also conducted radiometer temperature measurements in Bonn. Some of his results are shown in Fig. 2, which reproduces the daily mean value determined by him of the temperatures of extremely varied surfaces. The "least favourable" high temperatures are produced by stone, concrete and asphalt surfaces. It is apparent from the illustrations that surface temperature variation is at its least at sunrise, after which temperatures begin to rise at varying rates, and cool down again after sunset at varying rates and to different levels.

Urban superheating is generated by the stone, concrete and asphalt surfaces, whose "unfavourably" high mean temperature is clearly shown in the illustra-

tions.

b) Urban Surface Temperature Behaviour: Measurement of the surface temperature of overgrown areas presents us with problems, as the surface itself cannot be accurately defined. It must be remembered that the values recorded during radiometer measurement from vertically overhead are composed of data emanating from subsurfaces located between the surface of the ground and the upper vegetation level.

Measurements by airborne scanner produce the same problems. The surface temperature of large areas is made up of data determined over extremely diverse surface structures with very different thermal behaviour. It is impossible to determine the surface behaviour of every individual, small, homogeneous surface in an area covered: it is therefore necessary to simplify interpretation of the data acquired. This is achieved by using equidensities - average or approximate values - which must be considered in relation to the known thermal behaviour of characteristic homogeneous surfaces such as grass-covered areas, concrete, wooded areas and asphalt etc.

During the Summer of 1975, SVR organised four survey flights over the Essen area during the 24 hours between 7 and 8 August. From the data acquired, it was possible to determine the temperature behaviour of urban surfaces (Mahler and Stock, 1976).

First, for 50 selected areas, the type of use, surface-coverage density and the vertical extent of surface coverage were determined. The scanner data were then used to calculate the mean temperature of each surface at all four flight times.

Figs. 3 and 4 show the minimum and maximum surface temperatures. The difference between these produces the temperature-variation shown in Fig. 5.

All the examples shown display a rise in temperature with increased surface-coverage and building density, as shown in Fig. 7.

The temperatures for each affected surface were determined with the aid of isolevels: i.e., the distribution of surfaces radiating at the same temperature-level was determined and shown in 1.5°C steps (night) and 3°C steps (day). We therefore had a film record for each temperature step. It was also possible to determine the distribution across the surface and vertically over the temperature profile. In addition the results of the four flights along one profile directly East-West were digitized. The profile was made up of 10 areas, from which the vegetation proportion was determined, as shown in Fig. 6. On the other side, the IR channel was used to determine the areas of high thermal radiation. A distinct correlation between vegetation and temperature is apparent: the higher the temperature, the lower being the proportion of vegetation.

THE URBAN HEAT ISLAND

Proof of the existence of the Urban Heat Island has been demonstrated on

many occasions (WM 0,1974). When installing measurement stations and determining locations, a prior concern is that the different buildings in a town exert different influences on the values recorded. As early as 1885, Hann had already recognised that varying temperature differences between town and country arise not so much from the size of town, but are primarily related to the instrument siting. (Kratzer,1956). The variation between different building layouts, surface contouring and relative building density always produces varying effects on temperature behaviour.

Edmonds also writes (1954): "The validity of my purely mesoclimatic investigations could only be assured by siting (of the measurement equipment) so as to ensure that the area represented was also able to exert its full influence on the equipment." The measurements recorded are therefore determined by the measurement sites selected. The thermal radiation pictures can therefore be drawn on to determine these locations. However, if the detailed thermic composition of a town is known from the radiation pictures, it can be divided into areas of the same and/or different temperature. It would naturally be difficult to lay down such a division of the town area by absolute air temperature or humidity values, but it is certainly possible to determine the general levels and the climatic balance of the town from thermal radiation pictures. A decisive part is played by the ability to carry out area plotting, as the whole urban area provides readings at the particular instant of recording: we can thus compare different areas of the town with one another. Using conventional measuring techniques, this kind of comparison can only be made with great difficulty, and lengthy and expensive measurement-sequences are always necessary. From this, methods arise of applying surface-temperature radio-measurement techniques to the problems of urban and inhabited area meteorology and climatology (Lorenz,1973).

The town of Wuppertal, for example, lies in the Wupper Valley, and the effects of surface contour must therefore be taken into account when interpreting the thermal radiation readings.

In thematic charts of the urban area, we have attempted to weight the individual factors and to summate them, choosing the figures 1 to 3, where 1 represents favourable, 2 is neutral and 3 unfavourable.

The thermal distribution pattern noted during one night IR overflight divided the city into cold (1), warm (2), and very warm (3) zones. The contouring was divided into hilly (1), inclined (2), and valley-bottom (3) areas. The usage map distinguished between wooded (1), grassy (2), and built-up (3) areas, while the latter were further sub-divided into scattered (1), closely-spaced (2), and central (3) area building-densities. It will be seen from Fig.7 that the highest radiation temperatures were produced by the areas where the building density was highest. Heat-emitting heavy industrial installations also make their presence clearly apparent (Stock,1975).

The Ruhr Heat Islands are shown in Fig.8, and it can clearly be seen how

close they are to each other in the West. The towns of Duisburg, Oberhausen, Mülheim and Essen almost form one single Heat Island. The area becomes somewhat less densely-packed towards the East. Only the town of Dortmund is again apparent as a major Heat Island. Classification of this area with the aid of IR photographs and MSS data by the methods indicated above certainly produces important basic material for planning purposes. A first step is the recently-printed surface radiation temperature distribution chart of the Ruhr Area (Stock, 1976).

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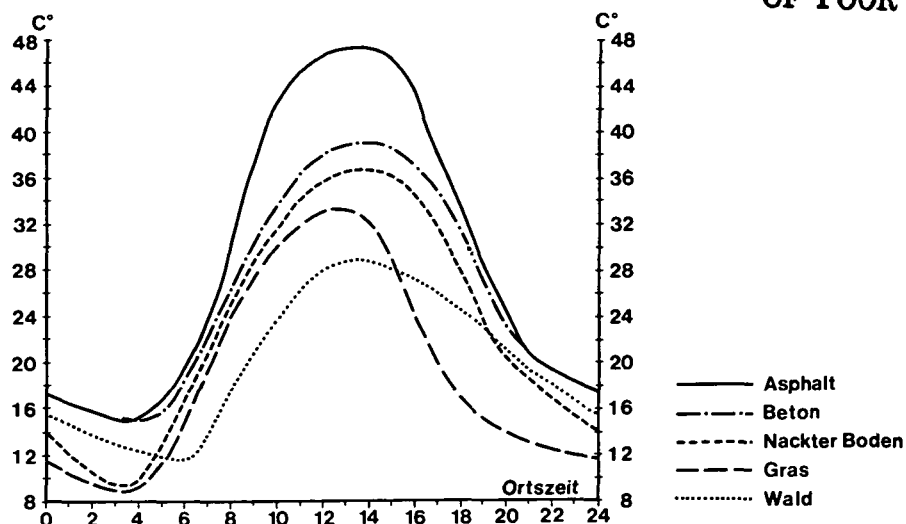


Figure 1: Radiation temperatures of different homogeneous areas (Fezer 1975).

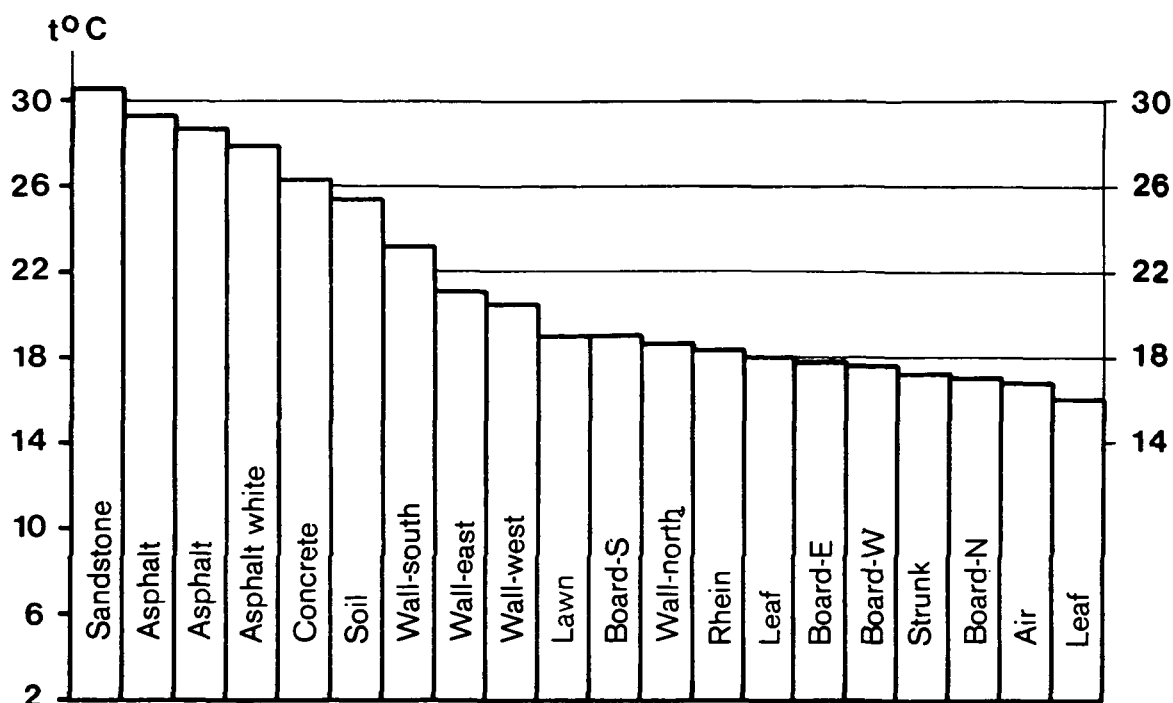


Figure 2: Daily mean of air - and surface radiation temperatures (Kessler 1971)

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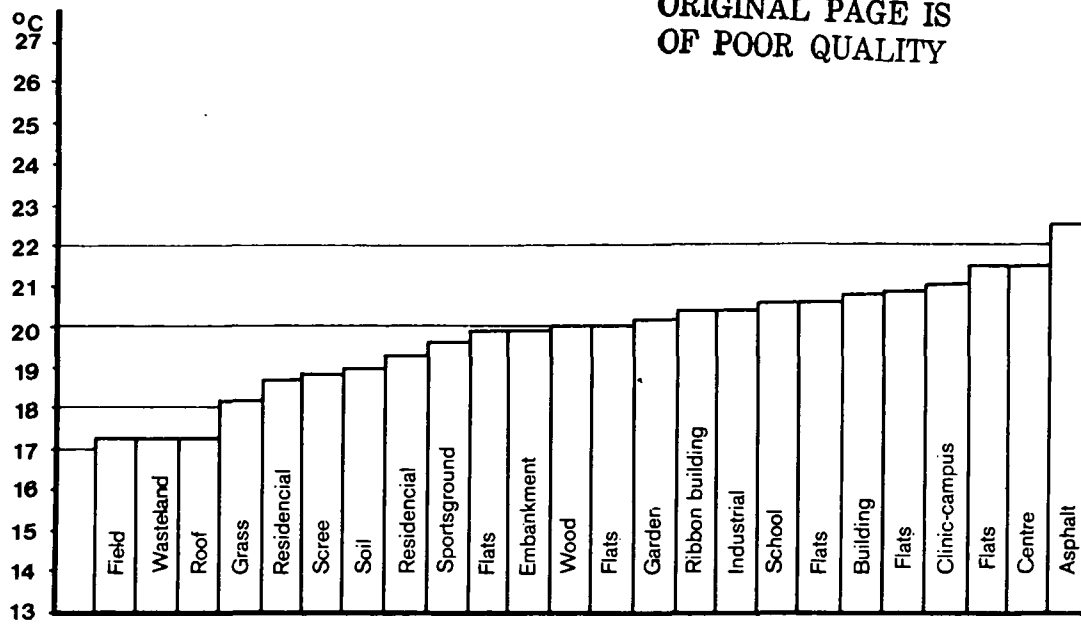


Figure 3: Radiation temperatures over different areas in Essen at night
8.8.1975, 4⁰⁰ h.

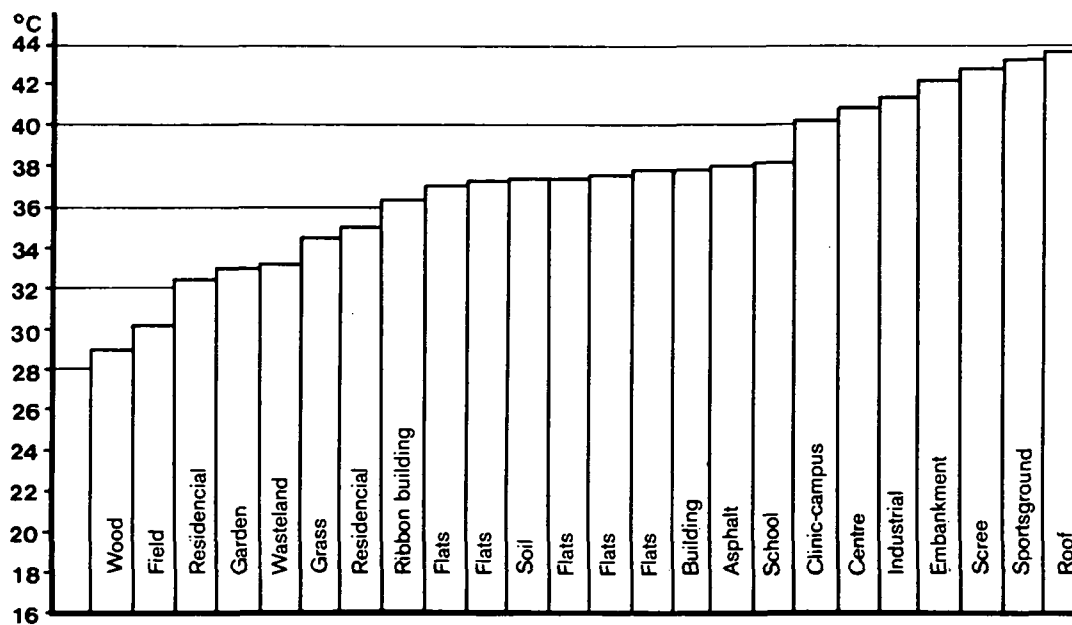


Figure 4: Radiation temperatures over different areas in Essen at day
8.8.1975, 10⁰⁰ h.

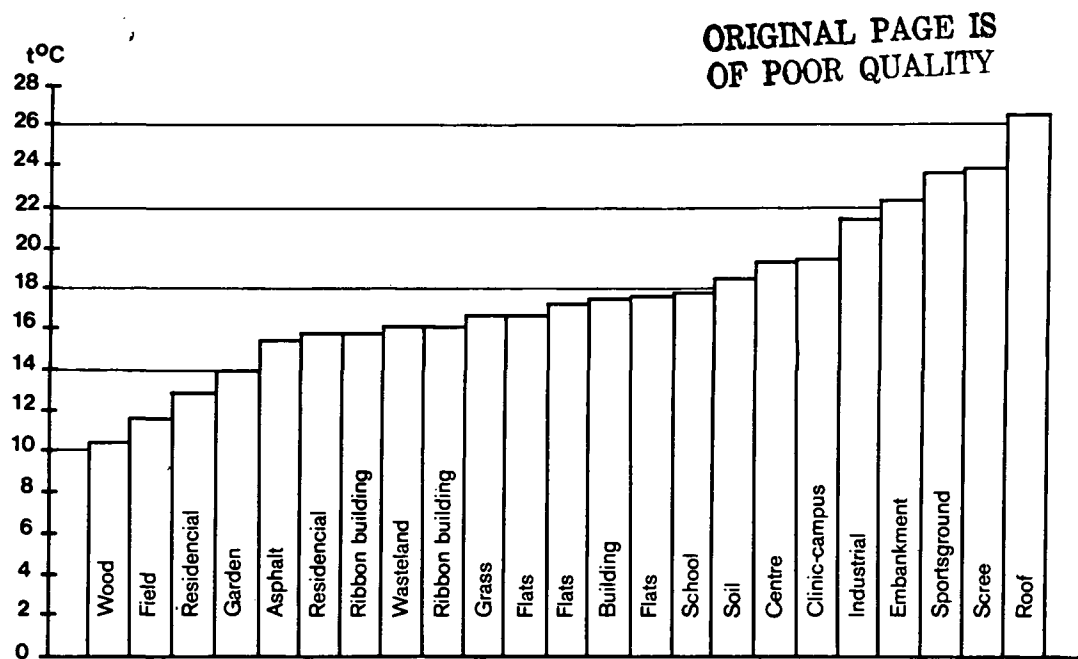


Figure 5: Increase of radiation temperature over different areas in Essen from night 8.8.1975, 4⁰⁰ h to day 8.8.1975, 10⁰⁰ h.

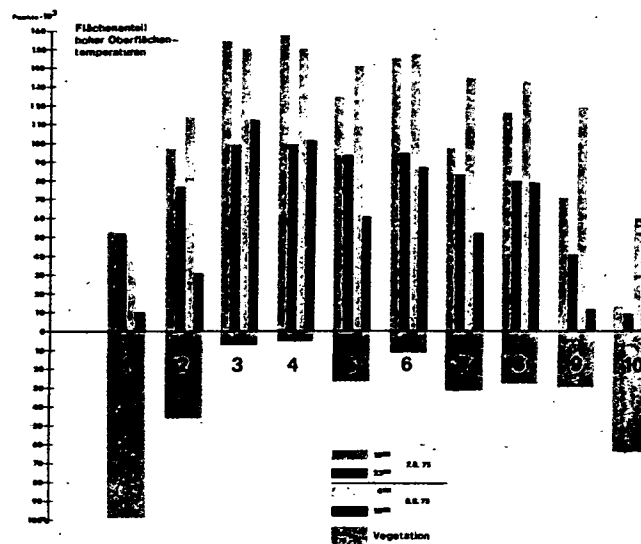


Figure 6: Relation between vegetation and radiation temperatures in 10 areas along a W-E-profile in Essen at 7. and 8.8.1975.

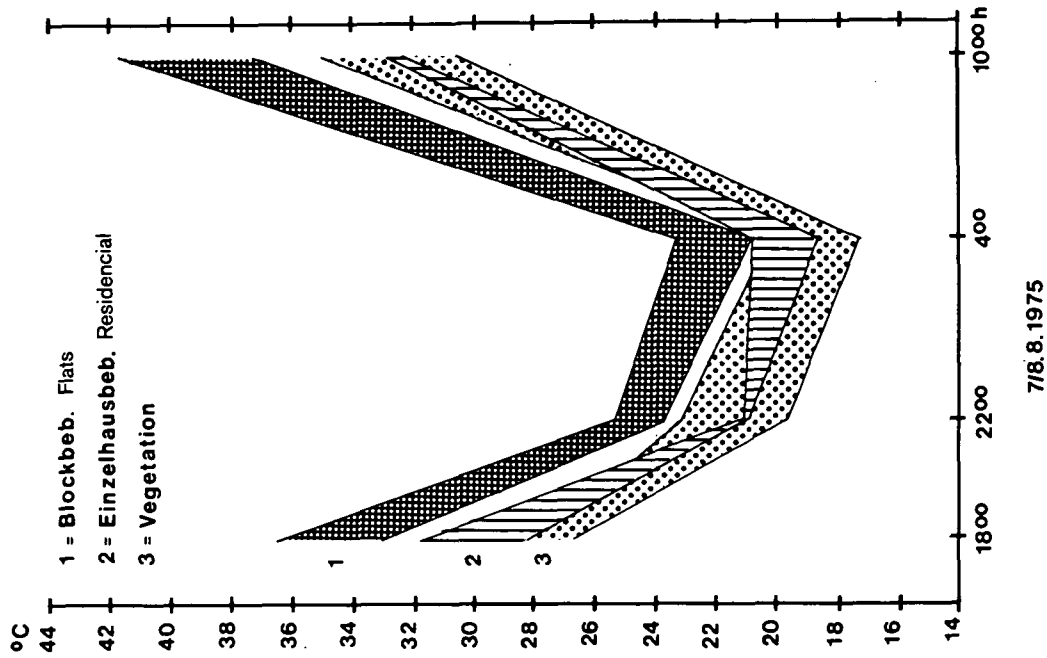


Figure 7: Radiation temperatures in Essen.



Figure 8: Heat-Islands in the Ruhr-District. Max. radiation temperatures at night 25.4.1973.

POTENTIAL APPLICATIONS OF DIGITAL, VISIBLE, AND INFRARED DATA

FROM GEOSTATIONARY ENVIRONMENTAL SATELLITES

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ABSTRACT

The National Environmental Satellite Service (NESS) is experimenting with an hourly, digital data base from the Visible/Infrared Spin-Scan Radiometer (VISSR) instrument on the GOES-1 and SMS-2 geostationary satellites. The general characteristics of this experimental VISSR data base (VDB) are described. Several examples of developmental applications of these quantitative digital data are presented. These include a review of recent attempts to develop products that are of use to meteorologists who provide services to aviation, agriculture, forestry, hydrology, oceanography, and climatology. The sample products include high resolution thermal gradients of land and ocean surfaces, thermal change analyses, fruit frost/freeze application, cloud-top altitude analysis, analysis of hurricane characteristics, and analyses of solar insolation. The poster session audience is invited to comment on the utility of these developmental products and to suggest applications that may be useful to the meteorological community services.

1. INTRODUCTION

The two geostationary satellites currently operated by NESS view the earth's disk through the VISSR instruments. Complete technical details of this dual geostationary satellite system are contained in the technical memorandum edited by Bristor (1975). This paper describes the general characteristics of the experimental VDB and presents examples of experimental applications of these quantitative digital data.

2. THE EXPERIMENTAL VISSR DATA BASE

The digital data from the VISSR instruments on the Western and Eastern satellites (currently GOES-1 located at 75W longitude and SMS-2 located at 135W longitude over the equator) are processed into an experimental VDB. These digital data may be obtained from each satellite at 30-minute intervals. The Western satellite's data are normally acquired at 15 minutes and 45 minutes after the hour. The Eastern satellite's data are acquired on the hour and half hour. The data from the full earth disk view are currently reduced to areas extending from 50N latitude to 38S latitude* and approximately 50 degrees longitude east and west of the satellite's subpoints. Thus, the VDB contains half-hourly digital data from the Western satellite representative of the area from 50N to 38S latitudes and 85W longitude to 175E longitude. Data from the Eastern satellite cover the area bounded by the same latitude range and from 25W to 125W longitudes.

The VISSR instrument provides concurrent observations in the infrared (IR) spectrum (10.5 to 12.6 μm) and in the visible (VIS) spectrum (0.55 to 0.75 μm). The IR and VIS digital data in the VDB are at a 7x7-km spatial resolution.

*This southern limit will be expanded to 50S when more computer storage is available in mid 1977.

The IR data are expressed as 8-bit count values that can be converted to equivalent blackbody temperatures. The VIS data are expressed as 6-bit count values that can be related to albedo values. The IR and VIS values are calibrated in terms of sensor output. Additionally, information is appended to the data that allows the values to be located with respect to the earth's surface.

The VDB is processed from data ingested in near real time and physically resides on four IBM 3330 disk packs that comprise a portion of the NOAA IBM S360/195 computer facility at Suitland, Maryland. The data are maintained for 24 hours in the experimental system. The characteristics of the experimental VDB are presented in Table 1.

3. POTENTIAL APPLICATIONS

The ability to retrieve quantitative digital data at half-hourly intervals opens a new world of potential applications. The absolute and relative changes in thermal and visible radiation patterns are available for quantification as to magnitudes of change, rates of change, departures from a specified or variable time average, time series analyses, etc. Derived quantities such as cloud cover and cloud-top altitude are open to analysis of their changes with time. Changes in surface thermal field can be analyzed on time and space scales that heretofore have been available only from a limited mesoscale network of conventional surface-based instruments.

4. TIME COMPOSITING

The arrangement of the data lends itself to the application of so-called "time compositing" techniques. This method takes advantage of the ability of the large-scale computers to store and fetch quantities very rapidly and efficiently. The method entails saving the warmest (darkest) or coldest (brightest) of the IR (VIS) values. A "save the warmest" composite over the ocean over an extended time period allows cold clouds to move through the scene and not affect the surface (warmest) values that are retained from each scene. The "warm" composite field contains only the warmest values viewed in the time sequence. Any "cold" areas remaining after a several-hour or several-day compositing period can be interpreted as areas of persistent cloudiness. A "save the coldest" composite results in a field that represents both the movement and vertical development of clouds. In clear areas, a "cold" composite can be used to show the movement of a cold air mass (for freeze-line analysis) and to show the areas of minimum radiative temperature.

5. EXAMPLES OF POTENTIAL APPLICATIONS

The Computer Techniques Branch (CTB) of the Sensor Processing and Applications Division of the NESS has been working with the Satellite Field Service Stations (SFSS's) (Washington, D.C., Kansas City, and Miami) and the Analysis and Evaluation Branch (A&EB) of NESS to determine the usefulness of the VISSR digital data from the VDB, as well as product needs that might be developed from it. The CTB has developed several digital products from the VISSR digital data accessed from the VDB and has made such products available to interested users at the SFSS's. The products are provided on a nonoperational basis for experimental evaluation and assessment. Examples of these products are displayed at the poster session and are explained below.

5.1. SEA SURFACE THERMAL GRADIENT ANALYSIS

Since the digital data are geographically registered in the VDB, data can be retrieved, processed, and displayed in near real time to any site operating with the NOAA 360/195 computer using computer printer alphanumerics. By specifying the picture time, latitude, longitude, and the dimension to be displayed, one could receive an alphanumeric array of both VIS and IR data. When a threshold of brightness in the VIS is assumed (or mapped) for land and cloud coverage, then the IR data can be screened pixel for pixel. This is possible since both the VIS and IR data are collocated in the VDB. Figure 1 is an example of this type of digital display.

5.2. SEA SURFACE THERMAL GRADIENT FROM TIME COMPOSITES

When the technique described above is applied over time and the warmest temperature saved, more extensive coverage is possible. This time compositing allows for cloud-edge, as well as partially clouded IR data, to be eliminated from the composite.

An experimental digital display of the Gulf of Mexico and the Coastal Zone of the Eastern United States is currently produced daily and sent to the Miami SFSS for use and evaluation. This composite uses four pairs of VIS and IR digital pictures with each picture pair separated by two hours. The sea surface thermal gradient alphanumeric display is sent via the National Hurricane Center (NHC) computer terminal. The experimental display is printed on eight pages of computer paper and represents coverage with about 8-km resolution. The product is used to position the Gulf of Mexico Loop Current and the Gulf Stream Wall. Figure 2 is an example of this composite and display technique.

5.3. ANALYSIS OF HURRICANE VISIBLE AND THERMAL CHARACTERISTICS

The use of digital VIS and IR data is also useful for making near real time hurricane rain- and flood-potential estimates. Currently, VIS and IR negatives or positive transparencies are analyzed at the National Hurricane and Experimental Meteorology Laboratory (NHEML) in Miami, Florida. Image data sent to the Miami SFSS are analyzed on a scanning, false-color, microdensitometer. The storm canopy areas are measured at three specified brightness thresholds of the sun-sensor-target normalized visible data (Griffith, et al., 1976) or three temperature thresholds for the IR data (Grube, et al., 1976). By accessing the VDB in near real time, image data and the microdensitometer processing are eliminated. To date, an experimental product has been provided NHEML, which "slices" the thermal IR digital data into three specified temperature regions, counts the pixels, and displays the IR on a computer printer using alphanumerics. Personnel at NHEML select the picture (VIS and/or IR) times (one up to eight, any combination) and the center latitude/longitude of interest for each picture time. Software is submitted via NHC's computer terminal. The digital data are selected from the VDB (1,000x1,000-km area each picture time) as NHEML directs, processed, and returned to NHC Miami.

Last year, several examples of this product were sent via computer to NHEML. For this hurricane season, NHEML will select pictures from the VDB on an experimental basis using software developed specifically for this purpose by the CTB at NESS. Figure 3 is an example of this product.

5.4. CLOUD-TOP HEIGHT ANALYSIS

When the height/temperature relationship is known at a location, the height value can be assigned to thermal IR digital data. The CTB has developed a cloud height display technique that utilizes RAOB data located in NMC's observation file, the VDB, and computer printer alphanumerics to produce the cloud height display.

Thermal IR data are retrieved from the VDB for a given latitude/longitude and array size (i.e., area). The latest radiosonde observation closest to the center latitude/longitude of the digital IR is extracted from NMC observation file. A height/temperature relationship is then obtained from the radiosonde pressure-height/temperature profile data. Using computer printer alphanumerics, height values are assigned each pixel of the IR data based on the height/temperature profile information. Successive "pictures" of the IR height display allow for differences in the scene to be analyzed and displayed temporally, spatially, and in vertical extent. This product is one of the initial digital satellite products being developed by NESS/CTB for the AFOS system of NWS. Figure 4 shows an example of this type of display.

5.5. SCENE CHANGE ANALYSIS BY TIME SERIES

Digital IR, when taken from the same location over time, can be analyzed for scene change characteristics. When cloud-only IR is analyzed in this fashion, then movement and growth (both vertical and horizontal) can be displayed.

The CTB has only recently begun to develop scene change display techniques. Two products under development are cloud-top height change and surface thermal IR scene change. Image data have suggested that surface heating patterns of clear areas may be key zones from which convective activity develops later in the day. Digital scene analysis can map, not only the areas of influence but also, the relative changes of visible and thermal characteristics of the area.

5.6. SURFACE THERMAL FIELDS RELATED TO THE FROST LINE

Changes in the thermal IR over land with time have also been used to monitor freeze events in fruit crop growing regions. This past winter enhanced IR pictures were sent to the Ruskin, Florida, WSO through the Miami SFSS. The image data, specially enhanced, showed the ground location of the freeze line and the temperature distribution on either side of the line. These data, along with other ground data, have been used to provide a frost warning service to farmers and fruit growers in Florida. The digital thermal IR data from the VDB were also provided researchers of the joint NASA/NWS/NESS University of Florida study. Since the Ruskin WSO is not serviced by the NOAA 360/195 computer, which contains the VDB, data were mailed to cooperators for evaluation and assessment.

The digital thermal IR from the VDB was found to be much superior than the enhanced IR images. Plans are now underway to provide the Ruskin WSO with a dial-up computer terminal to access the VDB directly, via RJE (remote job entry) using software and display algorithms developed by the CTB. This will allow near real-time access to digital thermal IR on freeze event nights.

5.7. SOLAR INSOLATION ESTIMATES

An experiment is planned for the summer of 1977 to investigate methods for determining surface insolation from satellite and ground-based meteorological data. This experiment will collect coincident satellite, meteorological, and pyranometer measurements over the portion of the Great Plains bounded by the 29N and 49N parallels of latitude and the 95W and 105W meridians.

The data collection procedure is illustrated in Figure 5. The Great Plains will be divided into targets 0.5 degrees latitude and longitude on a side (about 50-km square) and data collected for each target. A minimum of six to eight observations distributed over daylight hours will be made each day. The data will be collected for 60 days, although the days will not necessarily be consecutive.

Shortwave solar radiation incident on the earth is either reflected to space, absorbed in the atmosphere, or absorbed by the earth's surface. Surface insolation, the quantity of interest, is a function of incident solar radiation, and the amounts of energy reflected to space and absorbed by the atmosphere.

The fraction of incoming radiation that is reflected to space is primarily controlled by cloud amount and cloud thickness, both of which can be estimated from satellite data. Cloud amount will be computed by the two-threshold method (Shenk and Salomonson, 1972) in which the number of pixels in clear, partly cloudy, and cloudy classes are weighted to yield percentage cloud cover. The clear threshold is obtained by regression against functions of local solar zenith angle and the azimuth angle between satellite and sun. The mean brightness of the clouds is determined by averaging the count value of all pixels brighter than the cloudy threshold. Mean target brightness will also be computed for another measure of reflected radiation.

The amount of incoming radiation that is absorbed in the atmosphere is controlled by cloud cover, atmospheric moisture, dust, and the atmospheric mass traversed by the beam. Precipitable water and surface pressure are available from NMC and together with the cloud characteristics should provide enough information to account for radiation absorbed by the atmosphere. The precipitable water and surface pressure will be accessed from NMC fields whose resolution is lower than the one-half degree grid used for the Great Plains.

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TABLE I. THE EXPERIMENTAL VISSR DATA BASE (VDB)

SATELLITE	SUBPOINT	ACQUISITION TIMES	ACQUISITION INTERVALS	DATA COVERAGE	DATA RESIDENCE TIME
East (GOES-1)	75W	On the hour and half hour	30 min	50N-38S; 25W-125W	24 hrs
West (SMS-2)	135W	15 minutes and 45 minutes after the hour	30 min	50N-38S; 85W-175E	24 hrs

Sensor Data Characteristics:

DATA TYPE	SPECTRAL INTERVAL	UNITS	CONVERTIBLE TO	NOMINAL SUBPOINT SPATIAL RESOLUTION
IR	10.5-12.6 μ m	8-bit count values	Equivalent blackbody radiative temperatures	7x7 km
VIS	0.55-0.75 μ m	6-bit count values	Albedo	7x7 km

Other Characteristics:

- Earth location and calibration information are appended.
- Resides on four IBM 3330 disk packs in the NOAA IBM S360/195 computer system.
- Currently, some 55 of the possible 144 pictures are processed.
- Data volume is approximately 7×10^8 bits per 24 hours.
- The processing system, format, and data coverages are experimental and, thus, subject to interruption at any time by operational priorities and requirements.

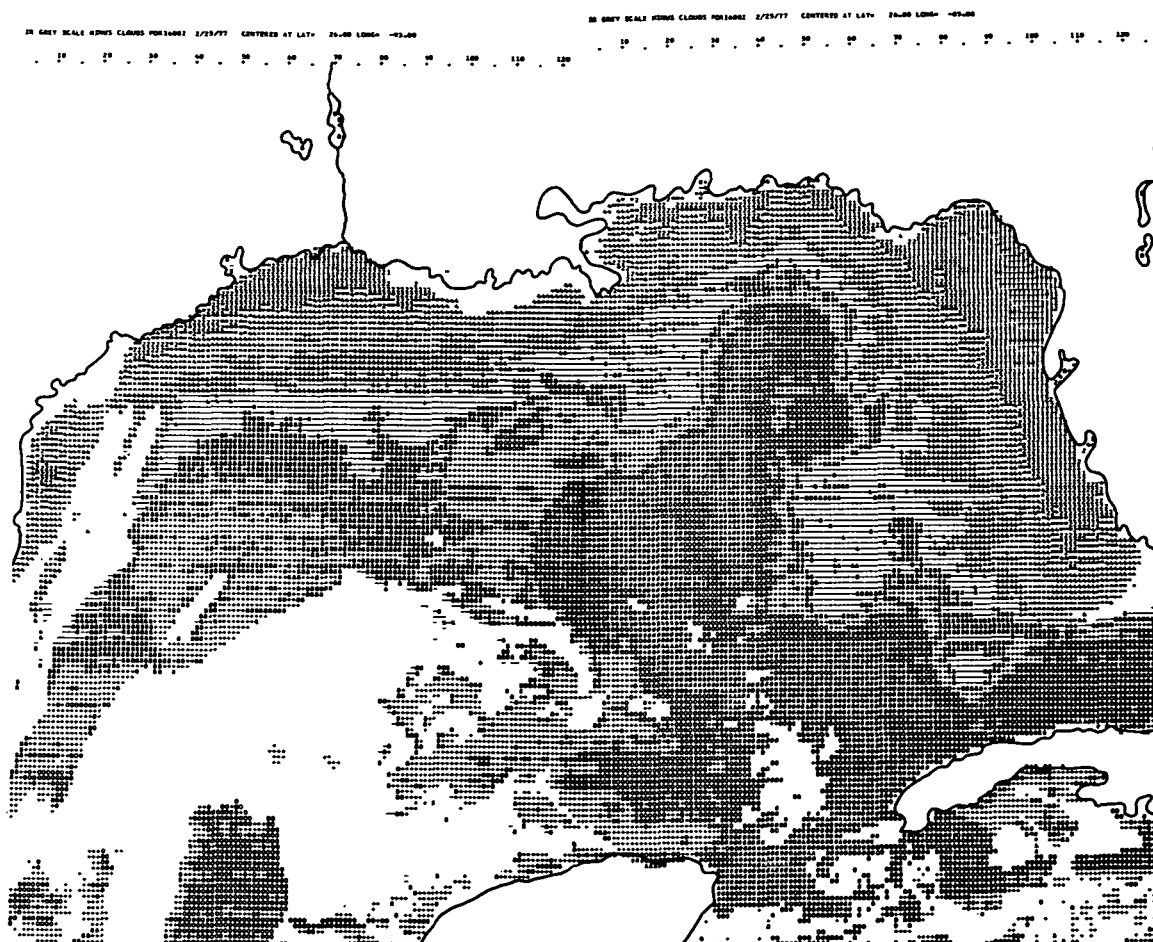


FIGURE 1.--SEA SURFACE DIGITAL GRADIENT DISPLAY OF THE GULF OF MEXICO LOOP CURRENT. Thermal IR digital data were taken from the GOES-1 satellite at 1600 GMT of February 25, 1977. Area displayed is the Gulf of Mexico with States bordering the Gulf, a portion of Western Cuba, and the Northern Yucatan Peninsula outlined by solid black lines. White areas in the display are either land, shallow water areas, or cloud-covered regions at picture time.

INFRARED EASY SCALE COMPOSITE PICTURE PORIMAGE TO 2000Z 2/25/77 CENTERED AT LAT= 20.00 LONG= -93.00
 INFRARED EASY SCALE COMPOSITE PICTURE PORIMAGE TO 2000Z 2/25/77 CENTERED AT LAT= 20.00 LONG= -93.00

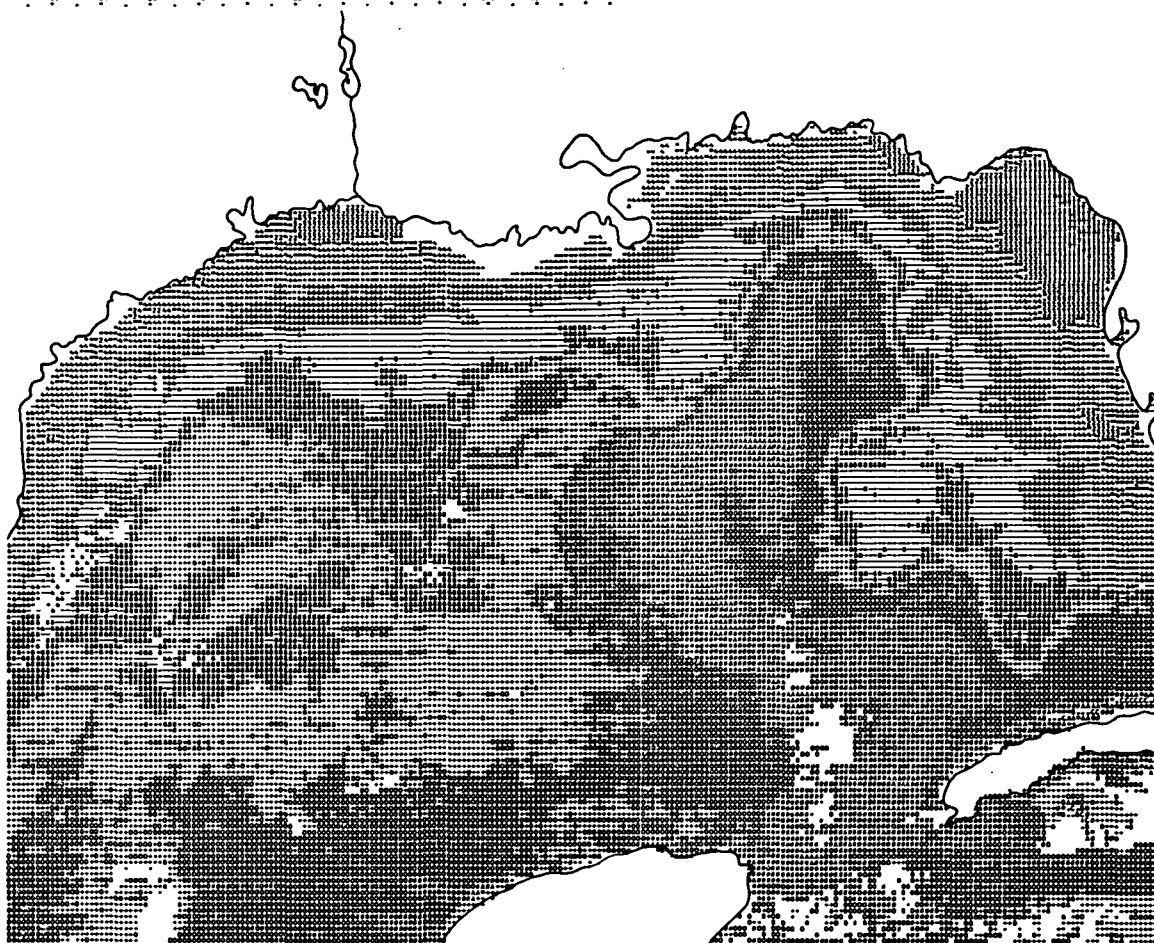


FIGURE 2.--SEA SURFACE DIGITAL GRADIENT DISPLAY OF THE GULF OF MEXICO LOOP CURRENT USING TIME COMPOSITING TECHNIQUES. Thermal IR digital data were taken from the GOES-1 satellite at 1400, 1600, 1800, and 2000 GMT of February 25, 1977. Area displayed is the Gulf of Mexico with States bordering the Gulf, a portion of Western Cuba, and Northern Yucatan Peninsula outlined by solid black lines. White areas in the display are either land, shallow water areas, or persistent cloud-covered regions at the different picture times.

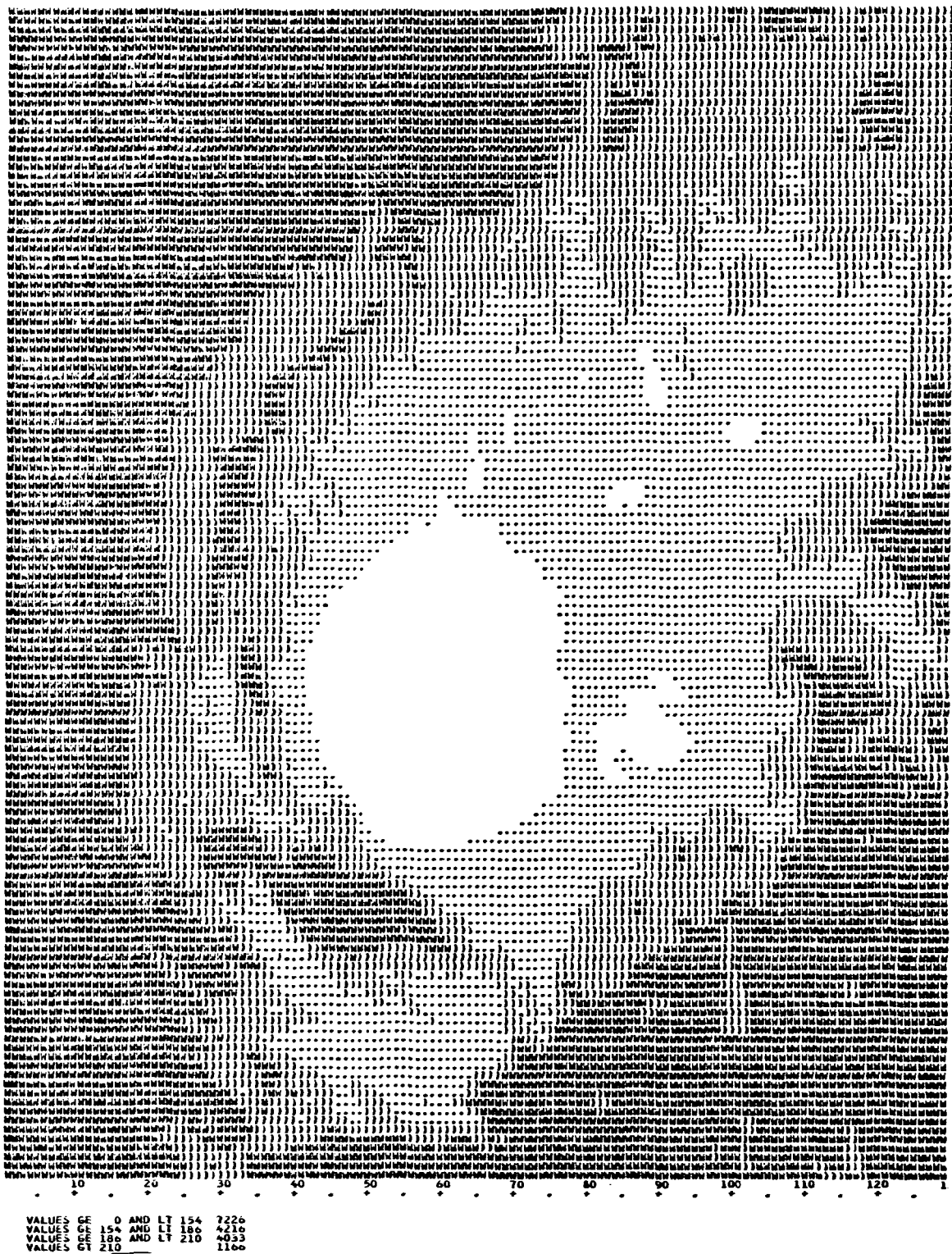


FIGURE 3.--THERMAL IR DIGITAL DISPLAY OF STORM CANOPY SLICED INTO FOUR DIFFERENT REGIONS FOR ESTIMATING RAIN AND FLOOD POTENTIAL BY THE NATIONAL HURRICANE AND EXPERIMENTAL LABORATORY, MIAMI, FLORIDA. Data displayed were taken from SMS-2 of storm located 22.0N,110.0W at 1545 GMT on October 28, 1976.

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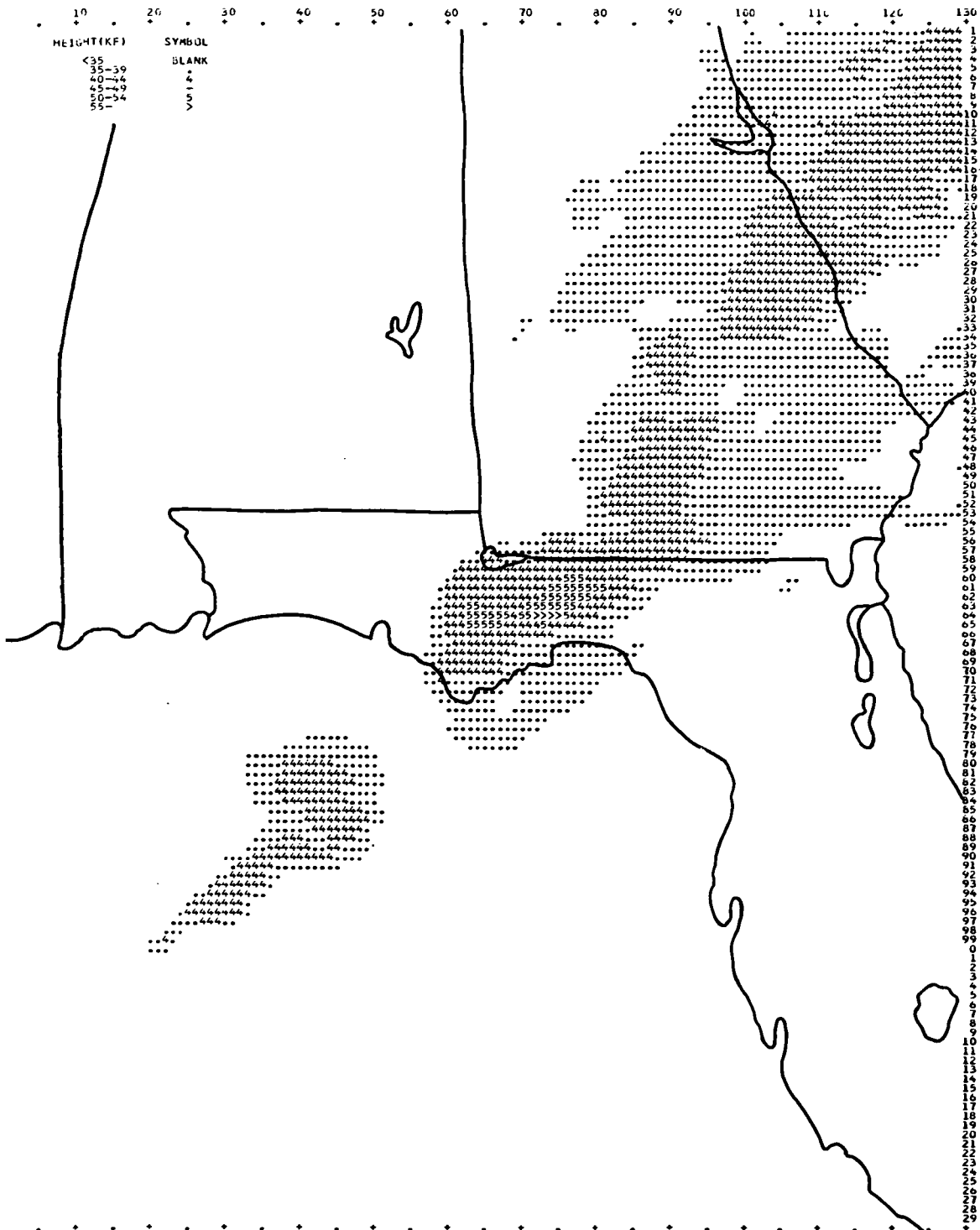


FIGURE 4.--THERMAL IR DIGITAL HEIGHT DISPLAY OF CLOUD SYSTEM, WITH EMBEDDED THUNDERSTORMS, IN THE SOUTHEASTERN UNITED STATES. Data, centered at 30.0N, 85.0W, were taken from GOES-1 at 1600 GMT of March 4, 1977. White areas in the display are either cloud heights below 35,000 feet or clear areas. Symbol table is located at upper left of display.

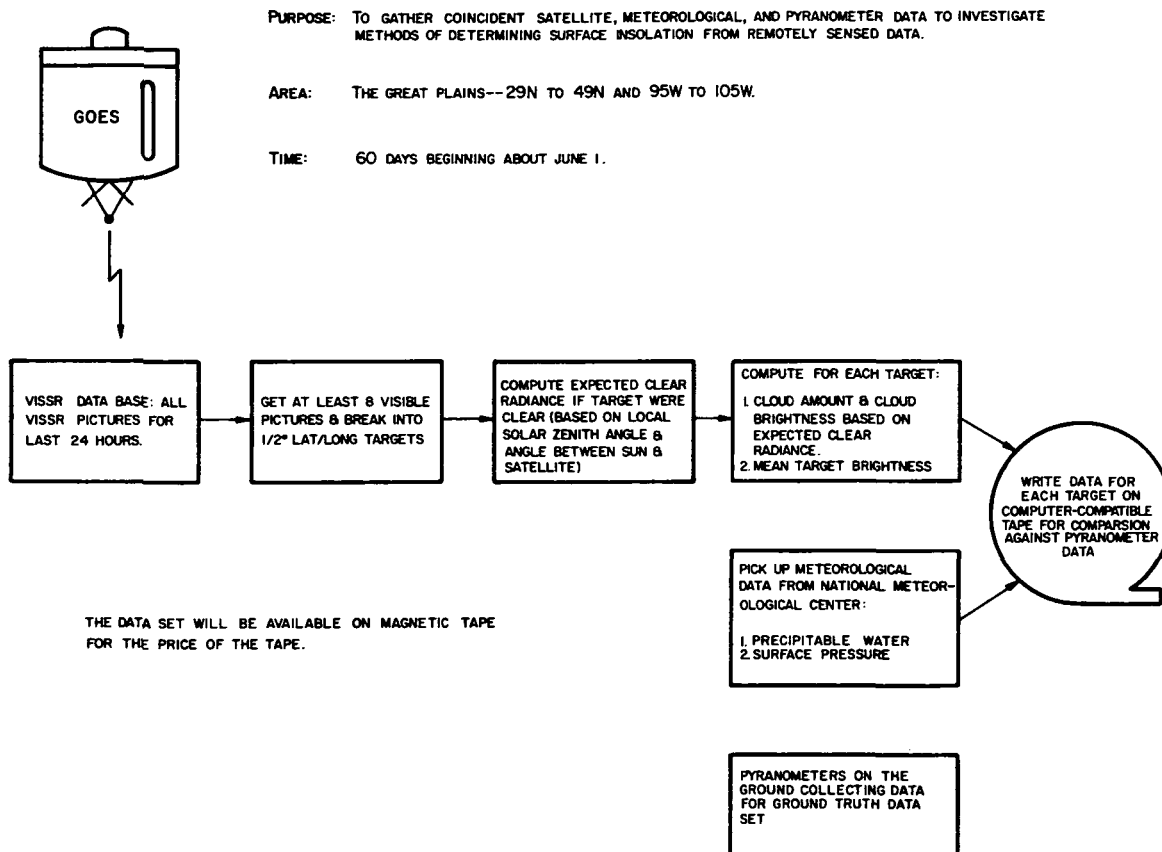


FIGURE 5.--ILLUSTRATION OF DATA COLLECTION PROCEDURE FOR INSOLATION EXPERIMENT TO BE CONDUCTED IN THE SUMMER OF 1977.

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STUDY OF THE BRAZIL AND FALKLAND CURRENTS USING THEIR IMAGES OF NIMBUS V ANDOCEANOGRAPHIC DATA IN 1972 TO 1973

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ABSTRACT

An oceanographic study of the Western Edge of the Sub-tropical Convergence of the South-western Atlantic Ocean, called the Front, which is a thermal discontinuity between the Brazil and Falkland Currents, was done utilizing the Temperature Humidity Infrared Radiometer (THIR) of Nimbus V in the 10.5 to 12.5 μm channel and historical oceanographic data in the period of 1972 to 1973. Some important results obtained are: the oceanographic Front could be detected from Nimbus V THIR data: oceanographic charts clearly showed that the transition zone where the Brazil and the Falkland Currents meet, was the Front detected from satellite data; ocean current speeds calculated with THIR data were of the same order of magnitude as those calculated oceanographically; fisheries statistics for Pargo Róseo showed that the maximum catches were in September of 1973, in the period when the Front was observed most distinctly and clearly. The results showed the great potentiality of satellite data to study surface thermal structures, surface currents and oceanic fisheries.

I. INTRODUCTION

The area of study is located at the western edge of the South Atlantic Sub-tropical Convergence, where the boundary (also called the Front) between the Brazil and Falkland Currents has been observed. The approximate coordinates are from 25° to 45°S latitude, and from 45° to 65°W longitude, whose oceanic part was estimated to be $2.5 \times 10^6 \text{ km}^2$ (Fig. I.1). The Brazil Current, carrying water of high temperature and high salinity, is a southern branch of the South Atlantic Equatorial Current. The Falkland Current, which sometimes is considered a branch of the South Atlantic West Wind Drift Current, extends northwards along the Coast of Argentina to about 35°S, where it meets the southwestern moving Brazil Current. The Falkland Current carries water of low temperature and low salinity of the Subantarctic region.

The boundaries between the cold and the warm currents have been found to be good fishing areas (Uda, 1936 and 1952; Zusser, 1958; Laevastu and Hela, 1970; Hynd, 1968). The Falkland Current maintains a high phytoplankton biomass and has been found to be one of the most productive areas of the world's oceans (Mandelli and Orlando, 1966). The greatest abundance of demersal fish exists in the southern Brazil at latitudes of more than 28°S (Yesaki, 1973). Besides, the Brazil and Falkland Currents are, at present, very poorly described in the existing literature. For these reasons it seemed that studying this current system could contribute significantly to fisheries and oceanography.

Many investigators have found that the surface boundary between warm and cold currents can be detected through remote sensing by studying the cloud-free images, either in the infrared and/or in the visible wavelength region, (Allison and Kreins, 1970; Maul, 1972 and 1974; Maul and Gordon, 1973; Stevenson et.al., 1974; Stevenson and Miller, 1972; Szekiolda, 1972; Szekiolda and Mitchell, 1974). With the Temperature Humidity Infrared Radiometer (THIR) of Nimbus V satellite, 10.5 to 12.5 μm channel, it has been possible to detect the pronounced temperature gradient of the surface boundary between the warm Brazil and the cold Falkland Currents; sometimes to observe clearly the difference of the two water masses associated with them and in some cases to visualize the complexity of their mixing. The objectives of the study are summarized as follows:

- 1 - To visually interpret the available cloud-free Nimbus V THIR (10.5 to 12.5 μm channel) images from the end of 1972 to the end of 1973 in the study region.
- 2 - To describe the most outstanding features of the boundary and the two water masses of the Brazil and Falkland Currents.
- 3 - To describe possible displacement of the currents and attempt to visualize the Mixing processes of the associated water masses from the comparison of successive images.

- 4 - To compare the Nimbus THIR data with the oceanographic data available from the Data Bank of INPE.

II. METHODOLOGY

152 cloud-free images of Nimbus V (see Table II.1), Temperature Humidity Infrared Radiometer (THIR), 10.5 to 12.5 μm channel, were used for this study. The boundary of the Brazil and Falkland Currents was primarily determined by visual interpretation of enlarged photographs. In this way a boundary line (or Front line) was obtained for every image. 75 boundary lines, obtained from enlarged photographs rated as excellent, were superimposed in Mercator map into 12 groups according to 12 time periods of the year, i.e. four seasons and each season being subdivided into three time periods called the first, the second and the third periods respectively. Each period was further subdivided into three shorter periods called early, middle and late periods. Each short period covered approximately 10 days. Image-100 (General Electric Company, 1975) was used to help the visual interpretation, in those cases indicated in Table II.1.

The oceanographic data of temperature, salinity and dynamic height were used to supplement the interpretation of the boundary. More than two thousand oceanographic stations distributed over ten time periods were selected for this study. The first two variables - temperature and salinity - were considered as the ground truth (sea truth) and compared with the results obtained from image studies. The dynamic height was used to calculate the geostrophic current in order to get an idea of the possible movement of the boundary. The study was done at first to describe the outstanding characteristics of the Front in each period, and then to compare these with the oceanographic data. Due to the time and the scale differences between these two approaches (satellite and conventional oceanographic data) and the errors (measurement, assumptions, approximations) involved, only the comparison of the order of magnitude of the quantities was emphasized, rather than their absolute values.

In order to better describe the Front, the study area was divided into three regions as defined in the previous work (Tseng, 1974), i.e. the northern region, the central region and the southern region. The northern region extends from 30° to 34°S latitude and from 48° to 54°W longitude; the central from 34°S to 38°S latitude and from 51°W to 56°W longitude and the southern from 38°S to about 46°S latitude and from 50°W to 60°W longitude.

Some terms used in Section III have been defined in order to compare oceanographic and satellite data:

- Mean Front (or mean boundary or mean): the arithmetic mean of the Fronts (obtained from Nimbus V THIR data) in each period.
- Eastern Envelope: the line connecting the easternmost peaks (more oceanic part) of the individual boundary (obtained from Nimbus V THIR data) lines.
- Western Envelope: the line connecting the westernmost peaks (close to the coast) of the individual boundary (obtained from Nimbus V THIR data) lines.
- Eastern peakline: the line connecting the peaks of the (surface) isotherms (obtained from oceanographic data) in the eastern part (more oceanic part) of the study area.
- Western peaklines: the line connecting the peaks of the (surface) isotherms (obtained from oceanographic data) in the western part (close to the coast) of the study area.
- Transition zone: the zone lying between the Eastern and the Western peaklines.

III. STUDY OF THE FRONT WITH THIR IMAGES AND WITH OCEANOGRAPHIC DATA

Natural oceanographic phenomena such as the boundary between the Brazil and Falkland Currents is so important to oceanography and fisheries that, from space data, a cartographic description in 6 out of the 12 periods is given in this Section III. In this description, features such as the position of the Front in the various periods of the year, its geographical extension, its apparent East-West motion and its meanders, are discussed. An attempt was also made to compare the order of magnitude of the East-West possible displacement of the Front with respect to geostrophic currents. A comparison of the Front with oceanographic charts was done for those periods where oceanographic as well as satellite data were available. More detailed description of the Front and its comparison with oceanographic data can be found in Tseng (1976).

3.1 SUMMER SECOND PERIOD (FROM JANUARY 22 TO FEBRUARY 21, 1973)

Nine Front lines were selected from 20 cloud-free THIR images. Four of them were in the early as well as in the late period; one was in the middle period (Fig. III.1).

In the northern region, the Front was found on its mean position in the middle of the early period at an approximate distance of 160 km from the coast (curve 1), and reached its westernmost position (curve 5) in the middle period, with the minimum distance of 100 km from the coast. In general, the Front had a tendency of being more oceanic during the early and the late periods and was closer to the coast at the end of the early period and in the middle period. In almost all cases studied, its northern tip was hardly seen north of 32°S.

In the central region, the Front was found more oceanic in the middle of the early and the late periods (curves 1 to 2 and 6 to 7); while in the rest of the periods, it was much closer to the coast (curves 8 to 9). An outstanding meander existed in front of Rio de La Plata at about 37°S, throughout the whole interval of the study, having its radius of curvature of 400 km to its eastern side.

In the southern region, the Front was observed on its easternmost position with its southern tip reaching the longitude of 50°W in the early period (curve 1). In the rest of the period, its northern part stayed around the mean (curves 2 to 9), having small oscillations. However, its southern part had very wide fluctuations, especially at the latitude of 41°S. An outstanding meander existed around 53°W and 40°S with a radius of curvature of approximately 200 km on its western side.

The two Peaklines obtained from the oceanographic data were superimposed on the Front lines. The Envelopes and the Mean were properly located between the East and the West Peaklines in the northern and the central regions and showed a reasonable agreement between the satellite and oceanographic data (Fig. III.2). Some general characteristics of the Front obtained from both satellite and oceanographic data are outlined in Table III.1.

3.2 AUTUMN FIRST PERIOD (FROM MARCH 22 TO APRIL 21, 1973)

Nine Front lines were chosen from 20 THIR images studied in this period. Five of them were in the early period, one in the middle and three in the late periods (Fig. III.3).

In the northern region, only three Front lines appeared. The Front was found at its Mean in the early period (curve 1); at the end of the middle period, it was on its easternmost position (curve 6), and at the beginning of the late period, it reached the closest position from the coast with a distance of 90 km from it (curve 7).

In the central region, the Front was observed on its Mean in the early period (curve 1), was in the easternmost position with its southern edge still touching its Mean at the end of the early period (curve 5) and in its westernmost position at the end of the late period (curve 9). In general, the Front apparently had a tendency of being more oceanic at the end of the early period and in all the middle period, while it was closer to the coast in the late period.

In the southern region, the Front was observed at its Mean (curve 1) and was on its easternmost position at the end of the early period. Early in the late period, the Front reached its westernmost position (curve 8). Two meanders were observed throughout all of the period: one was centered at 38°30'S, with the center of curvature on the eastern side of the Mean; the other at 41°S with the center of curvature on the western side. Generally, the Front stayed more oceanic at the end of the early and middle period and closer to the coast in all of the late period.

The Mean and the two Envelopes also stayed between the Peaklines, up to 39°S, indicating a good agreement between the satellite and oceanographic data (Fig. III.4).

3.3 WINTER

3.3.1 WINTER SECOND PERIOD (JULY 22 TO AUGUST 21, 1973)

Four Front lines were chosen from seven THIR images studied. One of them was in the middle period; the other three in late period (Fig. III.5).

In the northern region, the Front was found at its Mean (curve 1) at the beginning of the middle period, maintaining a distance of 180 km from the coast and was on its easternmost position at the beginning of the late period (curve 2). A meander was found in front of Rio de La Plata, with its center of curvature to its western side and lasted for all of this period. The shift of the bending point of the Front Lines seemed to form an ellipse of 160km in the East-West direction and 50 km in the North-South direction, suggesting the presence of a counter clockwise oceanic eddy in this period (Fig. III.5).

In the southern region, the Front was observed on the west of the Mean (curve 1) at the beginning of the middle period, and on its easternmost position in the late period. Three meanders could be observed around 39°S, all with their centers of curvature to the east of the Mean. The southern tip of the Front could not be observed clearly south of 40°S. This was the shortest Front observed in the twelve periods of 1973 (See Table III.1). A comparison between satellite and oceanographic data was shown in Fig. III.6. The Eastern Peakline was not available in this case.

3.3.2 WINTER THIRD PERIOD (AUGUST 22 TO SEPTEMBER 21, 1973)

Twelve Front lines were chosen from 22 THIR images studied. Six of them were in the early period, two in the middle period, and four in the late period (Fig. III.7).

In the northern region, the Front was found at its mean position at the beginning of the early period (curve 1), on its westernmost position at the end of the early period (curve 5) and reached its easternmost position at the beginning of the middle period. The northern tip could be observed very clearly and distinctly down to 31°S in most of the cases studied.

In the central region, the Front was found on the easternmost position at the end of the middle period (curve 4) and on its westernmost position at the end of the late period (curve 12). Many meanders could be observed in front of Rio de La Plata in all of the period. In most of the cases, their centers of curvature stayed on the western side of the Mean.

In the southern region, the characteristics of the Front were quite similar to those in the central region, showing the complexity of the East-West oscillations and the meandering at the Front in all this period.

A comparison between satellite and oceanographic data was made, as shown in Fig. III.8. It was found that the Mean Front and the Envelopes stayed between the two Peaklines shown in this Figure. The calculated speeds of the geostrophic current in the East-West direction were, roughly, 0.7 and 0.4 km/hr at 34° and 36°S respectively: the same order of magnitude as those calculated from the Front lines (Table III.1).

3.4 SPRING

3.4.1 SPRING SECOND PERIOD (FROM OCTOBER 22 TO NOVEMBER 21, 1973)

Eight Front lines were chosen from nineteen THIR images studied. Five of them were in the middle period and three in the late period (Fig. III.9).

In the northern region, only one boundary line could be seen at distance of about 90 km from the coast. The northern tip could not be seen clearly in the latitudes north of 34°S.

In the central region, the Front was found on its westernmost position at the beginning of the middle period, and reached its easternmost position at the end of the late period (curve 7). A meander could be observed in the front of Rio de La Plata with its center of curvature to the eastern side of the Mean lasting for the whole period.

In the southern region, the Front was found on its easternmost position at the beginning of the early period (curve 2), and on its westernmost position at the end of the late period (curve 7). A meander could be observed at 40°S with the center of curvature to the west of the Mean. The fluctuations of the position of the Front were much wider in this period. The Mean and the two Envelopes did not lie between the two peaklines (Fig. III.10). This is the only exception from the six periods studied.

3.4.2 SPRING THIRD PERIOD (FROM NOVEMBER 22 TO DECEMBER 21, 1973)

Five Front lines were identified from eight THIR images studied. One of them was in the

early, one in the middle and three in the late periods (Fig. III.11).

In the northern region, the Front was found on its easternmost position at the end of the early period (curve 1) and reached its westernmost position at the beginning of the late period (curve 3) to a distance of 110 km from the coast. The fluctuations of the position of the Front were especially smaller when compared to other periods studied.

In the central region, the Front was found on its easternmost position at the end of the early period (curve 1) and it reached its westernmost position at the beginning of the late period (curve 3). A meander occurred in front of Rio de La Plata, with its center of curvature in the eastern side of the Mean, lasting for almost all the period. The amplitude of the oscillations of the Front was the smallest as compared to the other periods in 1973.

In the southern region, the Front was found on its westernmost position at the beginning of the late period (curve 3) and reached its easternmost position at the end of the late period (curve 5). A meander was found at about 40°S with its center of curvature on the western side of the Mean lasting for almost the whole period.

The Mean Front and the two Envelopes stayed completely between the two Peaklines showing a good agreement between the satellite and the oceanographic data (Fig. III.12).

IV. DISCUSSION

To study oceanographic current boundaries would need a large number of images and a lot of oceanographic data. The number of good quality images is limited by such factors as excessive cloud cover, noise in the spectral channel and/or detector, telemetry problems, grid point errors, etc. For these reasons, some periods in this study had a lot of good quality images, and others did not have enough. Besides the possible errors mentioned, two more factors should also be taken into account. The one is called microsurface effect; the other is the time difference between the measurements made by oceanographic methods and with satellites.

With respect to the first, it is known that a layer of less than 1 mm of water is opaque to infrared radiation from 8 to 14 μ m, and 98% of the absorption occurs in the first 0.1 mm of the layer (Ewing, et.al. 1960). This means that the observed infrared radiation emerges from the very top of the air - water interface (the microsurface), where transfer processes like evaporation, reflection etc., take place and also where microsurface properties, such as protein monolayer and dust or oil films, are significant. The sea surface temperature is defined by conventional methods as the mean temperature of a well-mixed layer at least several decimeters deep, which is in reasonable agreement with the nature of conventional sea surface temperature observations. Experiments have shown (Ewing, et.al. 1960) that the microsurface is approximately 0.6°K colder than the layer of 15 cm under the surface. It has also been observed that the microsurface is remarkably stable. Thus, under clear-sky conditions, radiometric measurements of sea surface temperature generally should be approximately 0.6°K lower than conventional measurements.

With respect to the second factor, it can be said that the THIR sensor scans the large area of the boundary in approximately ten minutes. In such a short period of measurement, not a single oceanographic station could possibly be taken. For oceanographic vessels to cover the same boundary area, they would have to stay months in sea, running distances of more than one thousand kilometers to make oceanographic stations. When these cruises end, oceanographers have to plot the data in a single chart for every property measured for the whole area. After that, a chart showing average conditions is issued. This chart, however, contains probably a larger distortion of the ocean structure than that obtained from the satellites for the same area.

The oceanographic information of this area, in a scale adequate to compare with satellite data (1:3500000 in this case), was poor and fragmentary. For this reason, an Atlas of oceanographic structure (Inostroza and Tseng, in preparation) was prepared, and was used as a basic historical document for the image study. This Atlas consists of 150 charts of temperature, salinity, oxygen and nutrients in four levels: surface, 50m, 100m and 150m. These charts represented the average monthly conditions, and were used as the ground truth for this study, because simultaneous ground observations corresponding to the satellite passages were not available. Since the average conditions of the open ocean do not change very much in this scale (almost in steady state, Pickard, 1963), the average monthly temperature charts could reasonably represent the ground truth data.

The results from the comparative studies between oceanographic and satellite data have been quite stimulating. Because not only the Mean Fronts, but also their Envelopes were located between the Eastern and the Western peaklines obtained from the oceanographic data. The zone between these two peaklines, defined as the Transition Zone, was the zone where all the oscillations of the Fronts during the period of 1972 to 1973, occurred. The Peaklines represented a permanent oceanographic reality of the southwestern Atlantic Ocean at the boundary of the Brazil and Falkland Currents (not yet described in the existing literature). The Eastern and the Western Envelopes were fully obtained from the satellite Nimbus THIR data. Why the positions of the Envelopes stayed practically between these two peaklines in almost all the cases and not out of them? The authors believe that the Fronts obtained from the satellite data in this region are in the zone where they belong to, that is to say, in the Transition Zone, because in this zone the temperature gradient, as measured by the sensor, exists. Then it could be stated that in spite of the errors involved in the present sensor capabilities and the variables in oceanographic and satellite data including time differences between the two data sets, oceanographic charts show that the sensors give the positions of the Fronts, where they should be, i.e., where the temperature gradients obtained from oceanographic data are.

Another idea, developed to correlate the oceanographic characteristics and the satellite data, was to estimate the current speed. The authors believe that to study the movement of the current is not easy at present, because the capabilities of the present sensors are limited. For this reason, charts of geostrophic currents were made, and their speeds were calculated and compared with those obtained from the satellite data (see Table III.1). Speeds of the currents obtained from the pilot charts cannot be properly compared with those obtained from the satellite and the geostrophic currents (the scale of pilot charts was $5^{\circ} \times 5^{\circ}$, while that of the satellite and the geostrophic currents was $1^{\circ} \times 1^{\circ}$). A careful comparison of the current speeds (E-W or W-E direction) calculated from the satellite and the oceanographic data showed that, at least at 34°S , they were practically equal in each corresponding period. Now, from the seven periods studied and nineteen individual values of speed (Table III.1), it was found that eighteen of them were between 0.2 km/hr (0.1 knot) and 1.7 km/hr (0.9 knot) (close to 95% of the cases studied), and only one value was 2.4 km/hr (1.4 knot). It can be said that the current speeds calculated from the satellite data are of the same order of magnitude from 0.2 to 1.8 km/hr (0.1 to 1 knot). As those calculated from the conventional oceanographic methods (in 95% of the cases) and, in some latitudes, these values are practically equal (in the case of 34°S , for instance).

A study of the commercial fisheries of Pargo Rõseo in the coast of Rio Grande do Sul demonstrated that the catches of this fish were maximum in September of 1973, with 5 million kilograms and, in the other months, the catches were much smaller (Yesaki and Barcellos, 1974). As the Front lines of the third period of winter, obtained from the satellite data, were very active and much wider in their fluctuations, the Front lines and their characteristics could be important factors that affected, directly or indirectly, those September catches. This would mean that detecting the Front might be an important subject to study in the future, that would give useful information for fisheries in this region.

V. CONCLUSIONS

Some important conclusions obtained from this study are summarized as follows:

1. Detailed analysis of seventy five THIR images (interpreted visually and some with Image-100) have shown clearly the existence of oceanographic Fronts in this study area.
2. The surface temperature charts obtained from the historical oceanographic data showed the existence of a series of peaks, associated with each isotherm in the west, as well as a series of peaks, associated with each isotherm in the East. The Western and the Eastern peaklines could be observed in all the periods studied. Obviously, the first (Western) is associated with the Falkland Current and the second with the Brazil Current. These Peaklines, which have not been described in the present literature, were considered as the permanent oceanographic reality in the study region. They were obtained completely from the pure oceanographic data. The Transition Zone was also obtained from the pure oceanographic data.
3. The Envelopes and the Mean Fronts were obtained from pure satellite data. In comparison with the oceanographic data, it was shown that these Envelopes and the Mean Front were practically located between the Western and the Eastern peaklines in each period. This is encouraging and useful as it shows similarity between the results obtained from conventional and from space oceanography.

4. Another relationship between the conventional and space oceanography became evident from the calculation of current speeds. The results showed that 95% of the current speeds, calculated from both methods, were of the same order of magnitude, and in one case, at 34°S latitude, the calculated speeds were practically equal in all the periods.
5. As pointed out earlier, the position as well as the characteristics of the Front lines can be important factors that might affect, directly or indirectly, the concentration of the fish. This fact supports the conclusion that the boundaries between the cold Falkland Current and the warm Brazil Current in the Southwestern Atlantic ocean are good fishing areas.

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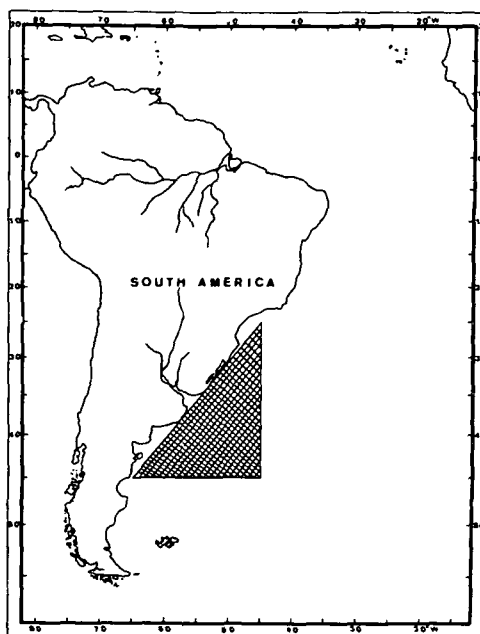


FIG. I.1 - AREA OF STUDY.

TABLE II.1 - LIST OF THE NIMBUS V THIR USED

ORBIT	DATE (DAY, MO., YR.)	SEASON	RATING	ORBIT	DATE (DAY, MO., YR.)	SEASON	RATING	ORBIT	DATE (DAY, MO., YR.)	SEASON	RATING	ORBIT	DATE (DAY, MO., YR.)	SEASON	RATING
0220 D	27.12.72	Summer 1	E	0945 D	19.02.73	Summer 2	F	2564 D	12.07.73	Winter 1	G	4045 D	08.10.73	Spring 1	F
0260 D	30.12.72	"	G	0977 M	22.02.73	Summer 3	F	2883 M	14.07.73	"	E	4059 D	09.10.73	"	F
0273 D	31.12.72	"	E	va 1025 D	25.02.73	"	E	3138 M	02.08.73	Winter 2	F	4078 M	11.10.73	"	G
0287 D	01.01.73	"	E	va 1052 D	27.02.73	"	E	3159 D	03.08.73	"	E	4091 M	12.10.73	"	E
0346 M	06.01.73	"	G	1119 D	04.03.73	"	F	3259 M	11.08.73	"	G	4099 D	12.10.73	"	G
0354 D	06.01.73	"	E	1334 D	20.03.73	"	F	3267 D	11.08.73	"	E	4112 D	13.10.73	"	G
0367 D	07.01.73	"	G	1339 M	21.03.73	"	F	3334 D	16.08.73	"	E	4118 M	14.10.73	"	E
0373 M	08.01.73	"	P	1365 M	23.03.73	Autumn 1	G	3353 M	18.08.73	"	G	4126 D	14.10.73	"	E
0381 D	08.01.73	"	E	va 1374 D	23.03.73	"	E	3374 D	19.08.73	"	E	4131 M	15.10.73	"	G
0394 D	09.01.73	"	E	1420 M	27.03.73	"	F	3420 M	23.08.73	Winter 3	F	4139 D	15.10.73	"	E
va 0421 D	11.01.73	"	E	1428 D	27.03.73	"	G	3468 D	26.08.73	"	E	4145 M	16.10.73	"	E
0467 M	15.01.73	"	P	1433 M	28.03.73	"	E	3487 M	28.08.73	"	E	4260 D	24.10.73	Spring 2	F
va 0475 D	15.01.73	"	E	va 1441 D	28.03.73	"	E	3495 D	28.08.73	"	E	4287 D	26.10.73	"	G
va 0480 M	16.01.73	"	G	1447 M	29.03.73	"	G	3508 D	29.08.73	"	E	4300 D	27.10.73	"	F
va 0488 D	16.01.73	"	E	1455 D	29.03.73	"	E	3514 M	30.08.73	"	G	4386 M	03.11.73	"	G
0534 M	20.01.73	"	G	va 1460 M	30.03.73	"	E	3522 D	30.08.73	"	G	4394 D	03.11.73	"	E
0542 D	20.01.73	"	E	1468 D	30.03.73	"	G	3527 M	31.08.73	"	E	4413 M	05.11.73	"	E
0609 D	25.01.73	Summer 2	E	1581 M	06.04.73	"	F	3535 D	31.08.73	"	E	4421 D	05.11.73	"	E
0622 D	26.01.73	"	E	1602 D	09.04.73	"	E	3554 M	02.09.73	"	G	4440 M	07.11.73	"	G
0628 M	27.01.73	"	G	1608 M	10.04.73	"	F	3562 D	02.09.73	"	E	4448 D	07.11.73	"	E
0636 D	27.01.73	"	E	1616 D	10.04.73	"	F	3573 D	03.09.73	"	G	4461 D	08.11.73	"	G
0649 D	28.01.73	"	E	1629 D	11.04.73	"	E	3629 D	07.09.73	"	E	4467 M	09.11.73	"	E
0735 M	04.02.73	"	G	va 1648 M	13.04.73	"	E	3656 D	09.09.73	"	G	4475 D	09.11.73	"	G
0743 D	04.02.73	"	F	va 1656 D	13.04.73	"	G	3710 D	13.09.73	"	E	4488 M	10.11.73	"	G
0749 M	05.02.73	"	F	1702 M	17.04.73	"	F	3729 M	15.09.73	"	F	4494 M	11.11.73	"	E
0757 D	05.02.73	"	G	1729 M	19.04.73	"	E	3750 D	16.09.73	"	E	4542 D	14.11.73	"	G
0762 M	06.02.73	"	G	1742 M	20.04.73	"	F	3782 M	19.09.73	"	F	4582 D	17.11.73	"	E
va 0770 D	06.02.73	"	E	1836 M	27.04.73	Autumn 2	F	3796 M	20.09.73	"	E	4588 M	18.11.73	"	E
0824 D	10.02.73	"	G	1863 M	29.04.73	"	F	3804 D	20.09.73	"	G	4609 D	19.11.73	"	G
0877 D	14.02.73	"	E	1970 M	07.05.73	"	E	3809 M	21.09.73	"	G	4628 M	21.11.73	"	G
0878 D	14.02.73	"	G	2051 M	13.05.73	"	E	3817 D	21.09.73	"	E	4722 M	28.11.73	Spring 3	F
va 0883 M	15.02.73	"	G	2064 M	14.05.73	"	F	3831 D	22.09.73	Spring 1	G	4730 D	28.11.73	"	E
va 0891 D	15.02.73	"	E	2091 M	16.05.73	"	F	3836 M	23.09.73	"	E	4864 D	08.12.73	"	E
0904 D	16.02.73	"	E	2118 M	18.05.73	"	F	3844 D	23.09.73	"	E	4910 M	12.12.73	"	E
0905 D	16.02.73	"	G	2252 M	28.05.73	Autumn 3	E	3857 D	24.09.73	"	E	4958 D	15.12.73	"	E
va 0918 D	17.02.73	"	G	2480 M	14.06.73	"	E	3871 D	25.09.73	"	E	4971 D	16.12.73	"	F
va 0931 D	18.02.73	"	E	2722 M	02.07.73	Winter 1	E	3898 D	27.09.73	"	E	5012 D	19.12.73	"	P
0937 M	19.02.73	"	G	2730 D	02.07.73	"	G	3903 M	28.09.73	"	F	5025 D	20.12.73	"	E

REMARKS: (1) - D: Daytime; N: Nighttime

(2) - Rating was divided into three classes: excellent (E), good (G) and poor (P).
Those of the excellent were chosen to study the Fronts in 1972 to 1973.

(3) - "va" Image-100 was applied.

(4) - "M" Grid Print Maps were applied.

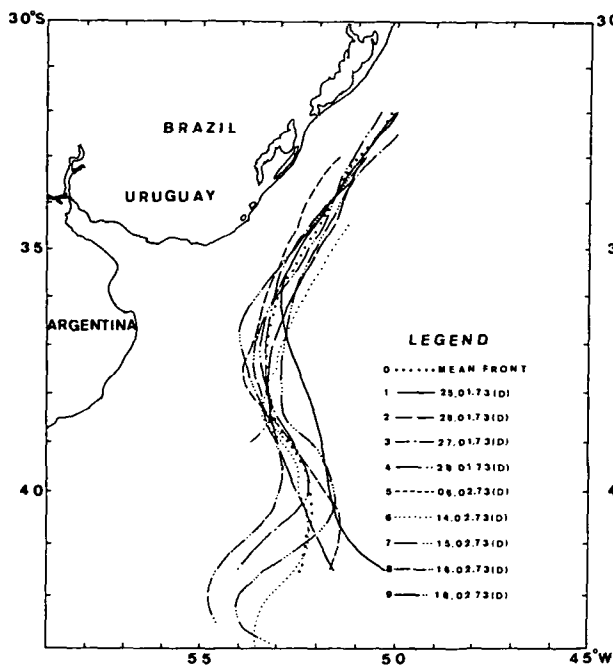


FIG. III.1 - FRONT LINES OF SUMMER SECOND PERIOD OF 1973.

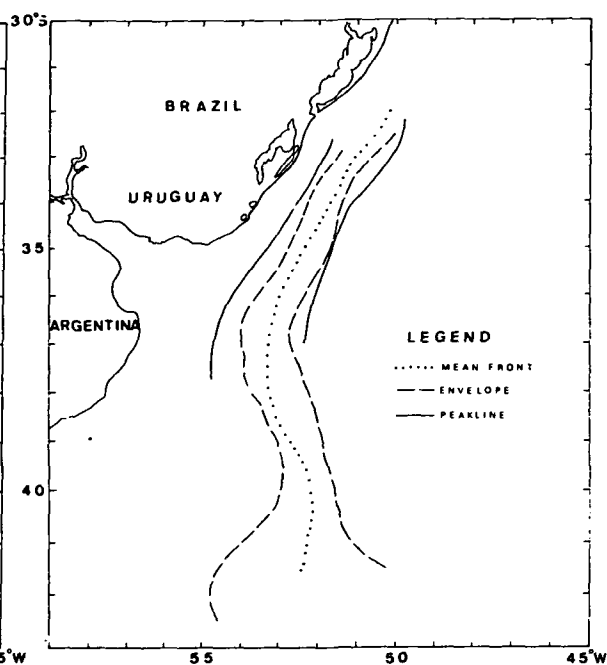


FIG. III.2 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF SUMMER SECOND PERIOD OF 1973.

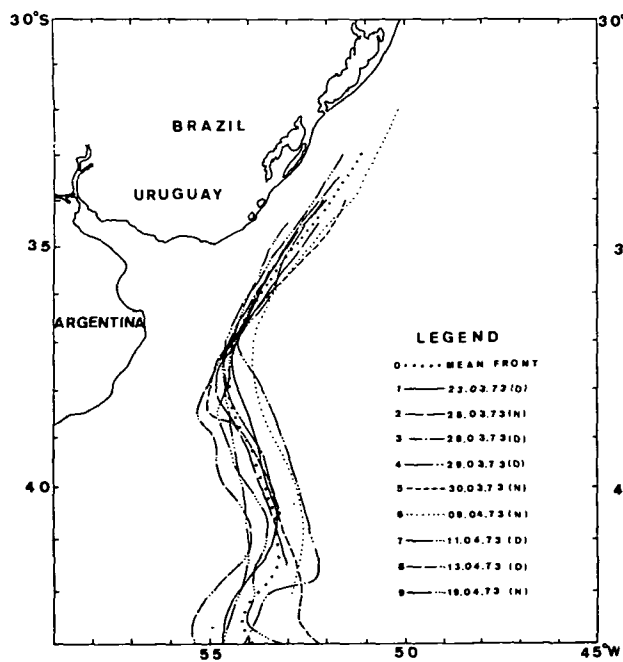


FIG. III.3 - FRONT LINES OF AUTUMN FIRST PERIOD OF 1973.

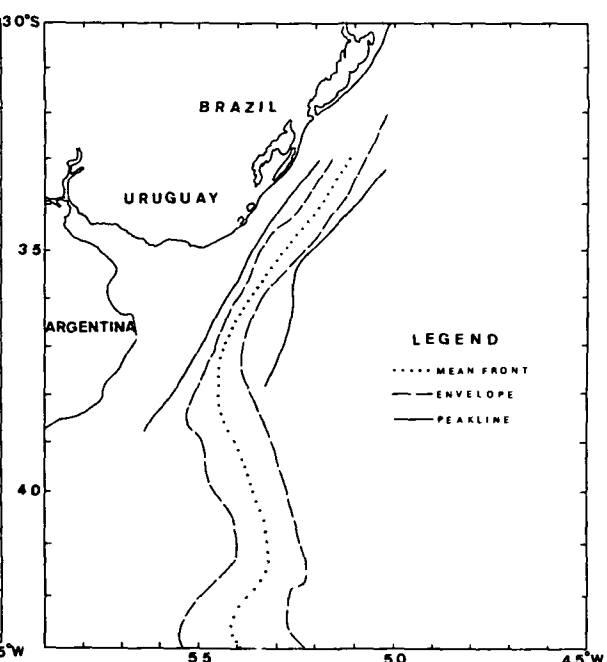


FIG. III.4 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF AUTUMN FIRST PERIOD OF 1973.

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TABLE III.1 - SOME GENERAL CHARACTERISTICS OF THE FRONT.

SEASON	PERIOD	LATITUDE	APPROXIMATE SPEED OF CURRENT (KM/HR) IN EAST-WEST OR WEST-EAST DIRECTION			APPROXIMATE NORTHERN AND SOUTHERN TIPS FROM NIMBUS V THIR (°S)	APPROXIMATE LENGTH OF FRONT FROM NIMBUS V THIR (KM)
			FROM NIMBUS V THIR	FROM OCEANOGRAPHIC DATA	FROM PILOT CHART		
SUMMER	1	31	-	-	1.1	32-43	1,220
		34	0.6	-	-		
		36	0.6	-	1.3		
		38	0.7	-	-		
		40	0.6	-	-		
	2	34	0.4	-	-	32-43	1,220
		35	-	-	1.1		
		36	0.6	-	-		
		38	0.4	-	-		
		40	0.7	-	-		
	3	32	-	-	0.7	32-41	1,000
		34	0.4	0.4	0.9		
		36	1.7	0.4	-		
		38	2.6	0.6	-		
		40	3.1	-	-		
AUTUMN	1	32	-	-	0.7	32-43	1,220
		34	0.6	0.2	0.9		
		36	0.4	1.1	-		
		38	0.9	0.7	-		
		40	0.7	-	-		
	2	31	-	-	0.6	34-43	1,000
		32	-	-	0.6		
		34	0.2	0.2	-		
		35	-	-	1.1		
		36	0.2	1.1	-		
	3	38	0.2	0.7	-	33-43	1,110
		40	0.4	-	-		
		31	-	-	1.1		
		33	-	-	0.9		
		34	0.2	0.2	-		
WINTER	1	36	0.2	-	-	33-43	1,110
		38	0.2	-	0.6		
		38	0.2	-	-		
		40	0.4	-	-		
		40	0.4	-	-		
	2	34	0.6	-	-	32-40	890
		35	-	-	0.9		
		36	0.7	-	-		
		38	0.7	-	-		
		40	0.7	-	-		
	3	33	-	-	0.9	30-43	1,450
		34	0.6	0.7	-		
		36	0.6	0.4	1.1		
		38	0.9	-	-		
		40	1.1	-	-		
SPRING	1	34	0.7	-	1.1	31-43	1,330
		36	0.4	-	1.1		
		38	0.7	-	-		
		40	0.6	-	-		
		40	0.6	-	-		
	2	31	-	-	1.1	33-43	1,110
		34	0.6	0.4	1.1		
		36	1.3	0.6	1.1		
		38	1.5	0.7	-		
		40	1.7	-	-		
	3	32	-	-	1.1	32-41	1,000
		34	0.4	0.4	1.1		
		36	0.2	0.6	1.1		
		38	0.2	-	-		
		40	0.4	-	-		

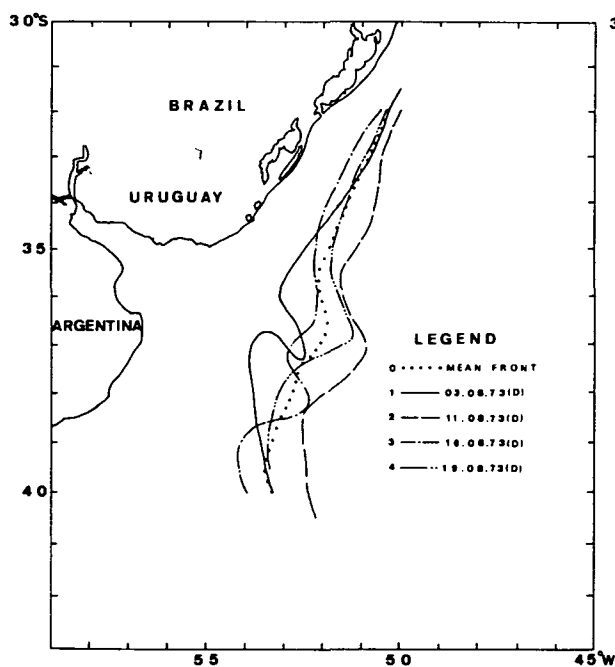


FIG. III.5 - FRONT LINES OF WINTER SECOND PERIOD OF 1973.

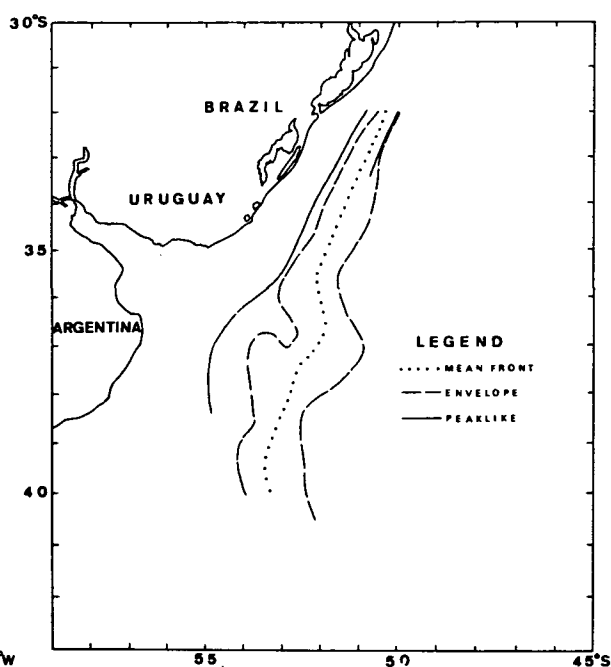


FIG. III.6 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF WINTER SECOND PERIOD OF 1973.

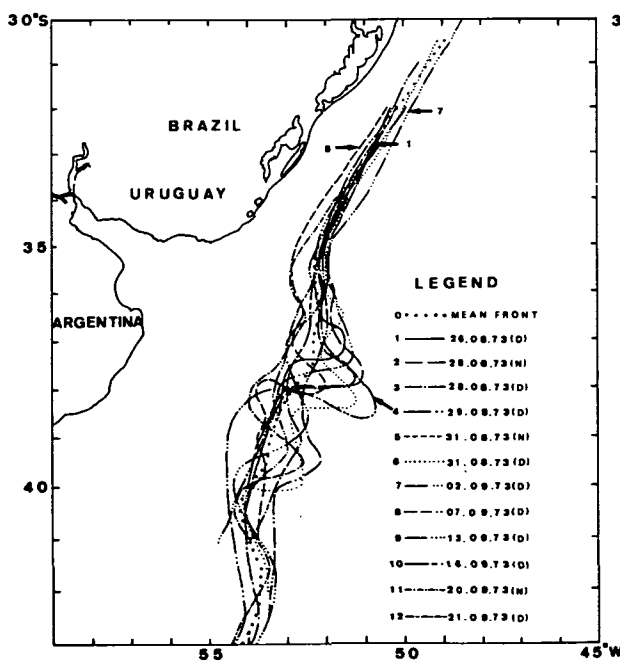


FIG. III.7 - FRONT LINES OF WINTER THIRD PERIOD OF 1973.

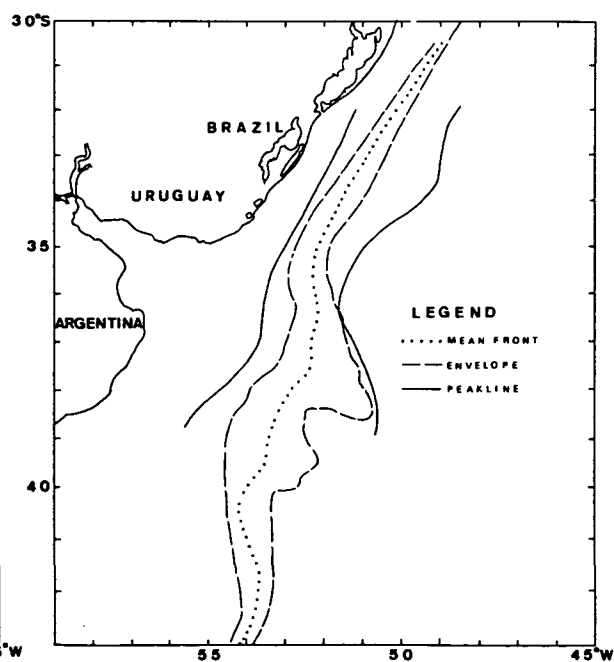


FIG. III.8 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF WINTER THIRD PERIOD OF 1973.

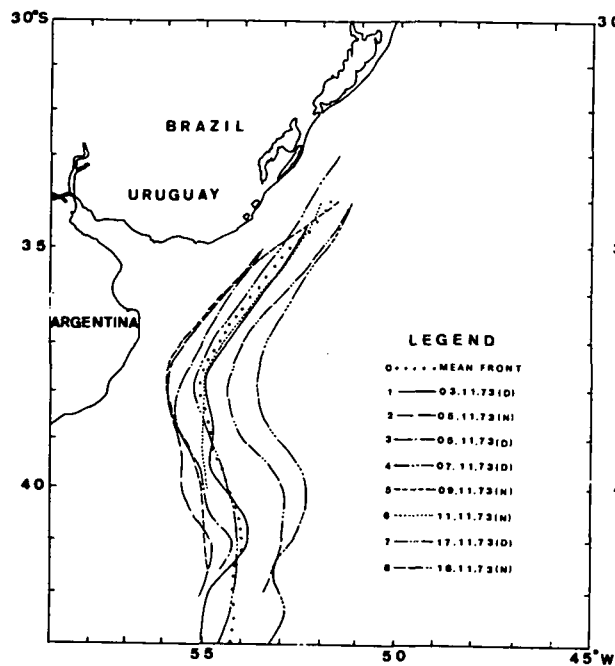


FIG. III.9 - FRONT LINES OF SPRING SECOND PERIOD OF 1973.

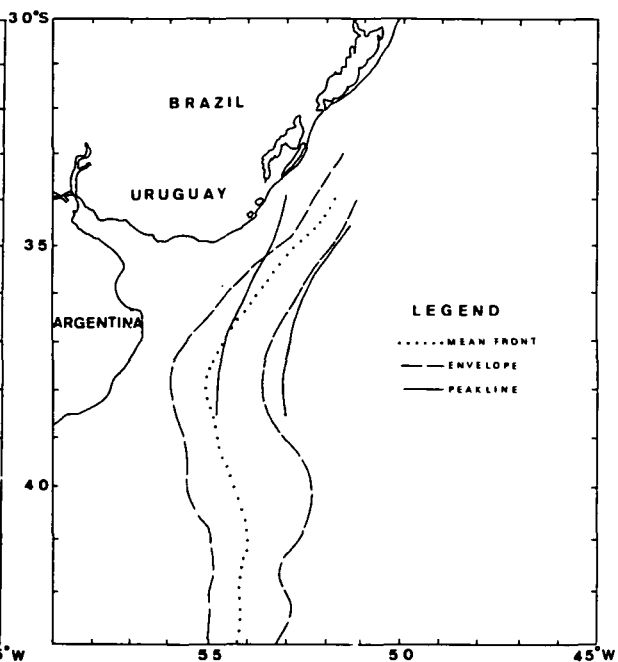


FIG. III.10 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF SPRING SECOND PERIOD OF 1973.

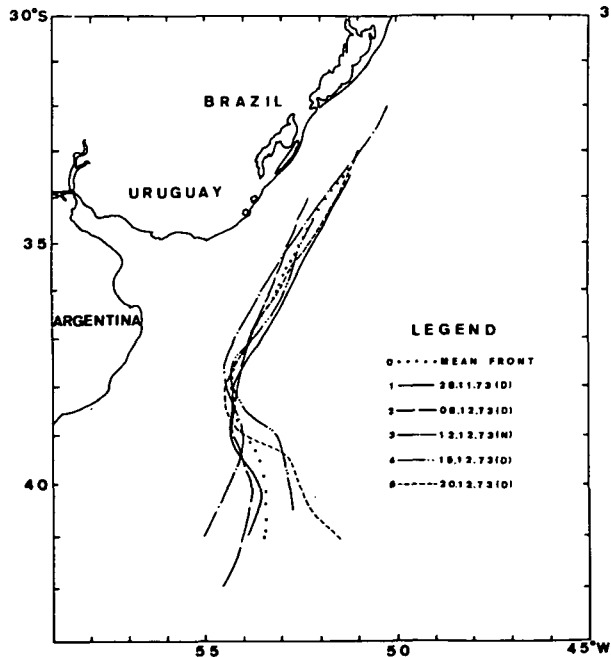


FIG. III.11 - FRONT LINES OF SPRING THIRD PERIOD OF 1973.

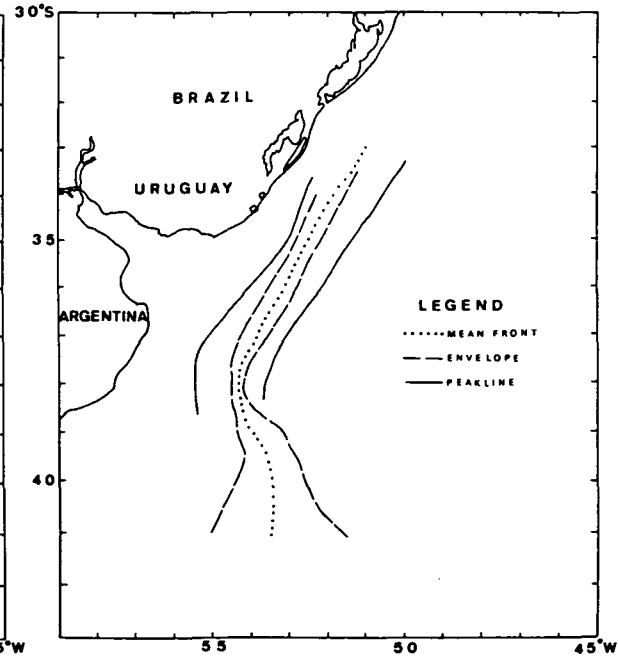


FIG. III.12 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF SPRING THIRD PERIOD OF 1973.

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NASA/COUSTEAU OCEAN BATHYMETRY EXPERIMENT

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SUMMARY

Experiment was conducted in the Bahamas between August 26 and September 8, 1975. The "Calypso" operated by the Cousteau Society and the "Beayondan" operated by personnel from the Applied Physics Laboratory, Johns Hopkins University were the two vessels from which the experimental team obtained supporting data on water transparency, bottom reflections, fathometer depths, and position information. LORAN-"C" equipment was used aboard the Calypso by arrangement with the U.S. Coast Guard.

NASA arranged for both Landsat 1 and 2 to be operated in the high gain mode in order to determine maximum depth and depth accuracies obtainable by satellite remote sensing. Applications to updating world navigational charts and mapping of changes in nearshore bottom topography are forecast based on results obtained.

Thirteen satellites were used during the experiment. Near real time transmission of Landsat derived data from NASA Goddard to the Calypso was successfully demonstrated. Near real time depth contouring from MSS-4 was also demonstrated at NASA Goddard.

Supported only by measurements of average water transparencies and bottom reflection data, Landsat Bands 4 and 5 were used to construct bathymetry maps of the test area near the Berry Islands.

Depths to 22 meters were reliably verified at accuracies within 10 percent of measured values. CCT signals two counts above deep water signals were identified to be caused by light reflected from 40 meter depths. Landsat data taken in October successfully gave reliably depths using experimental data taken a month earlier.

At 3X gain for Landsat-1, Band 4 was found to saturate a 1.3 meter depths and Band 5 saturated at .3 meter depth for high reflective bottom (about 30 percent in Band 4). These are acceptable since Band 5 can be used to cover range where Band 4 reaches saturation.

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LANDSAT DIGITAL DATA FOR WATER POLLUTION AND WATER QUALITY STUDIES IN
SOUTHERN SCANDINAVIA

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ABSTRACT

Spectral diagrams, illustrating the spectral characteristics of different water types, were constructed by means of simple statistical analysis of the various reflectance properties of water areas in southern Scandinavia as registered by LANDSAT-1. There were indications that water whose spectral reproduction is dominated by chlorophyllous matter (phytoplankton) can be distinguished from water dominated by non-chlorophyllous matter. Differences between lakes, as well as the patchiness of individual lakes, concerning secchi disc transparency could be visualized after classification and reproduction in black and white and in color by means of Line Printer, Calcomp Plotter (CRT) and Ink Jet Plotter respectively.

1. INTRODUCTION

Water quality studies were carried out by densitometer analysis of LANDSAT diapositives within different wave length bands at the Remote Sensing Section, Department of Physical Geography, University of Lund in 1974 (Helldén 1975). Thereby it proved possible to trace pollution plumes in the Öresund off Copenhagen and to obtain relative measures of the concentration distribution and circulation in the polluted water under different conditions. The results obtained also clearly indicated that there is probably a relation between the grey-tones of lakes within different spectral bands in LANDSAT imagery and secchi disc transparency of the same lakes. It was considered valuable for the continued work in this field to test the information bulk in LANDSAT CCT for the appraisal of water qualities by automatic data processing. Parts of Scania and the Öresund were chosen as test areas. The data used for the investigation were registered by LANDSAT-1 on Aug. 8, 1973 (1400-09410).

2. ERRORS AND THEORY

According to spectral investigations presented by Fitzgerald (1972) water pollutions and inorganic suspensions are characterized by a reflectance maximum in 0.6-0.7 microns (MSS 5) and then the reflectance falls rapidly with increasing wave length, while the spectral characteristics of phytoplankton are more complex. Generally speaking chlorophyll in water in the form of plankton absorbs effectively within the band 0.4-0.5 microns while reflectance is most intensive in the band 0.5-0.6 microns (MSS 4) with a secondary minimum in 0.6-0.7 microns (MSS 5) and a secondary maximum in 0.7-0.8 microns (MSS 6). The pre-requisite for a secondary maximum in MSS 6 is that the chlorophyll concentration reaches a lowest critical value in the water layers closest to the surface since the electromagnetic radiation in the near IR is almost entirely absorbed by the water molecules in the uppermost centimeters of the water body.

The radiation that is recorded by the satellite borne sensor system cannot be related to the radiation properties of the water exclusively, but the spectral properties of the atmosphere must also be taken into consideration. According to Farrow (1975) about 9%, on an average, of the radiation that reaches the atmosphere from the sun is back-scattered into space on a cloudless day. Of course, great deviations from this value may occur due to variations in solstice and composition of the atmosphere. Provided that 75% of the radiation emitted from the sun reaches a water mass on a cloudless day and that the water re-radiates 10% of the radiation, i.e. 7.5%, via the atmosphere into space, it is evident that the atmospheric radiation into space is of great importance since it makes up more than half of the radiation registered by the satellite. The atmospheric scattering, which is partially dependent on wave length (Rayleigh scattering) is most intensive in short wave lengths and, then, gradually decreases with increasing wave length. Thus, the atmospheric noise is strongest in MSS 4 where it can sometimes reach values that are equivalent to the re-radiation of the water, while it may be considered negligible in the near IR bands (MSS 6 - MSS 7) (Farrow 1975, NASA 1974).

In the present investigation no attempt has been made to quantify the effect of the atmosphere or solstice on the radiation recorded by LANDSAT-1 since the study is based on analyses of one LANDSAT scene only. When studying water quality, using LANDSAT data, over long periods and at registrations from different times during the year, these factors should be taken into consideration.

3. DATA AND METHODS

3.1. DIGITAL PROCESSING OF MULTISPECTRAL DATA

Basic research regarding digital processing of pictorial information has been carried out at the National Defence Research Institute (FOA) since the 1960s and in 1973 this activity was extended to comprise multispectral data.

The computer processing has been carried out at the Stockholm Computer Center, using an IBM 360/75 and also using a PDP-11/40 at FOA. As a necessary complement to the image processing the FOA computer has special equipment for input and output of image data, for example three-colour TV, ink jet plotter and instruments for converting a transparent film to a digital image or, vice versa.

FOA have several routines for the conversion of data. These routines are all part of the process to convert data of different original types and from different storage medium to a form which can be used as a standard routine.

An important part of the digital processing also consists of manipulations of separate spectral bands, e.g. when transforming digital data in order to improve the image. Amongst other things it is interesting to investigate the amount of picture elements with a certain digital value and to present them in the form of histograms or to present pixel by pixel of the digital values registered. Other

manipulations which may be used are, for example, writing only one or a few selected digital levels with one of the image recorder units available, including line printer, colour coding of the digital levels in a spectral band or, in advanced processing to use Fourier transformation technique for the analysis of any regular geometric forms in the image. Routines for all this manipulations, and others, are implemented, or can be included as intergrated parts of the program system for the processing of multispectral digital data at FOA, even if its main purpose is simultaneous processing of several 'image layers'. True multispectral processing must also be based on knowledge of the statistical characteristics of image data. In this case routines are required for the calculations of, for example, mean values, variances, co-variances and correlations, generation of scattering diagrams etc.. Where generation of images is concerned, colour images can, naturally, be created where separate spectral bands can be given separate colours and also composite images in the form of the difference or the quota or more complicated mathematical relations between the pixels which correspond to the same ground point. Special forms of statistical pre-processing are required for automatic classification, i.e. the determination of which "class" the pixel belongs to according to rules known in advance and in relation to known type objects or in relation to groupings of similar pixels which are determined during the course of the calculation. These processing routines are also implemented in the program system in question. A detailed examination of the available processing routines are beyond the scope of this report. Please refer to separate reports for the description of this program system and its application (Gustafsson and Åkersten 1976, Orhaug and Åkersten 1976 a, b, Orhaug et al. 1976).

3.2. METHODS OF EVALUATION

After the selection of subscenes and the definition of extensions by determination of corner co-ordinates (line number and pixel), the statistical grey-tone distribution for the spectral bands MSS 4 - MSS 7 could be presented in the form of histograms and symbol coded plots. The distribution of pixels over digital grey-tone levels (DGL) for different types of water was automatically evaluated and represented in diagrams. Mean values and standard deviations were calculated at the same time. The latter formed the basis of the construction of spectral diagrams for the study of spectral characteristics of different water qualities.

In order to visualize differences in water quality grey-tone maps (line printer plots), Calcomp Plots (CRT) and color plots (Ink Jet Plotter) were produced. Using the line printer for production of grey-tone plots up to nine different grey-tones can be reproduced simultaneously, while up to 15 grey-tone levels can be reproduced at the same time in a calcomp plot. The ink jet plotter has the capability of producing color images directly on ordinary paper. By forcing ink under high pressure through a fine nozzle, small drops of ink are produced. A

suitable voltage charges the drops which can be modulated by a control electrode. With three ink systems having different colours (magenta, yellow and cyan) color images can be produced. The one available at FOA can be fed directly from the computer or from a tape drive. It plots six pixels per millimeter in the colors mentioned independently modulateable to 15 intensity levels. Current output format allows a 1024 x 1536 pixels image to be plotted on a drum in about 90 seconds.

4. RESULTS

4.1. THE COPENHAGEN AREA

Today most of Copenhagen's waste water is discharged unpurified by two pump stations into the Eastern part of Kongedybet at a depth of 6-10 m. The pump station situated in the North discharges about 14 mill. m³ waste water per annum, while the corresponding quantity for the pump station in the South is about 40 mill. m³/year (Dackman et al. 1971). Besides the sewers mentioned two day-water sewers start from Strandvaenget, which, on Aug. 27, 1973, served as sources of the waste plume furthest to the North registered by LANDSAT-1 (Helldén 1975). The extension of the plumes and presumed concentration distribution are shown in Fig. 1. The iso-lines, which are supposed to be a relative measure of the particle concentration of the discharge plumes, were drawn with the help of a symbol coded line printer plot in MSS 5. The grey-tone distribution in the water areas near the coast on all plots reflects not only the varying particle concentration of the water but probably also the varying depth of water (Fig. 2-3).

4.2. LAKES RINGSJÖARNA

As investigation area and subscene number two the lakes Östra Ringsjön, Västra Ringsjön and Sätöftasjön were chosen.

The differences in water quality between and within the three lakes were visualized by production of plots of the above mentioned types (Fig. 5-6). The plots can also be said to illustrate the extent to which a measurement of the secchi disc transparency carried out in situ in any one of the lakes is representative of the lake in question. In other words, the applied methodology may be useful for obtaining an idea of the patchiness of lakes regarding their secchi disc transparency. The great variations in reflectance in the different bands, within and between the registered lakes, can probably be referred to algae blooming. The light strakes, which are most distinct in Lake Östra Ringsjön in MSS 6 and MSS 7, are interpreted as accumulations of blue-green algae in the most superficial water layers.

4.3. THE LAKES NW YSTAD

As investigation area and subscene number three the Lakes Krageholmssjön, Ellestadssjön, Snogeholmssjön and Sövdesjön were chosen. The spectral description and varying water quality of the lakes are dealt with under the following heading.

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4.4.COMPARATIVE SPECTRAL ANALYSES

Spectral diagrams were constructed for the respective investigation areas in order to carry out comparative studies of the spectral characteristics of different water qualities (Fig. 7-8).

4.4.1.THE COPENHAGEN AREA

The spectral functions of the water masses outside Copenhagen are characterized by having the highest DGL values in MSS 4 falling with a relatively steep gradient to MSS 5. In MSS 5 the gradient becomes more gentle and assumes a permanent value between MSS 5 and MSS 7. The position of the functions in the y-direction is supposed to provide a measure of the transparency of the water and consequently the digital grey-tone levels, especially in MSS 5, are supposed to give a relative measure of the particle concentration in the water. High values of DGL correspond to high particle concentrations. The spectral functions concerning the standard deviations of the waste plumes, on the whole display the same characteristics as corresponding functions for DGL mean values. The mutual positions of the functions are supposed to reflect the varying homogeneity (patchiness) of the different water masses regarding transparency and particle concentration.

4.4.2.LAKES RINGSJÖARNA

All the functions are characterized by assuming the highest DGL values in MSS 4 from where they fall to MSS 5 in relatively steep gradients. However, between MSS 5 and MSS 6 the gradients decrease and in one case even changes sign, but between MSS 6 and MSS 7 they resume values that are equivalent to the course of functions between MSS 4 and MSS 5. An embryo of a secondary maximum is thus seen in MSS 6 concerning A, B and C, a secondary maximum which is a reality for the function D; the latter reflects spectral characteristics of an accumulation of superficial plankton (algae) in Lake Östra Ringsjön. The above mentioned embryo or occurrence of a secondary maximum in DGL in MSS 6 is supposed to characterize chlorophyllous water. The appearance and mutual position of the functions are thereby thought to give information about varying algae concentrations and transparencies between the lakes.

The spectral functions concerning standard deviations are characterized by a minimum in MSS 5 and a maximum in MSS 6. The mentioned max. and min. are probably characterizing chlorophyllous and, where phytoplankton distribution is concerned, heterogeneous waters. The mutual positions of the functions reflect the varying homogeneity, patchiness, of the waters concerning transparency and algae concentration. All the functions diverge noticeably from the spectral functions of the Copenhagen area.

4.4.3.THE LAKES NW YSTAD

As in the case of the spectral functions of Lakes Ringsjöarna, the characteristics

of the lakes (A),(B),(C) and(D)are supposed to be a result of the presence of chlorofyll (phytoplankton) in the water bodies. However, the presence of chlorophyll in (B) seems to be almost zero. The presence of chlorophyll gives rise to increased reflectance values in MSS 6.Matter not containing chlorophyll in water does not give rise to such an increase (Cf the spectral diagrams of the Copenhagen area).The appearance and mutual positions of the functions are supposed to reflect varying algae concentrations and secchi disc transparencies between the four lakes.

The spectral functions regarding standard deviations are,as in the case of Lakes Ringsjöarna,characterized by a minimum in MSS 5 and a maximum in MSS 6. The min. and max. mentioned are supposed to characterize chlorophyllous and, regarding phytoplankton distribution,heterogenous waters.

5.CONCLUSIONS

The secchi disc transparency of the above-mentioned lakes was measured in situ between Aug. 8 and Aug. 27,1973 by means of a secchi disc.The registrations were carried out by the County Administration of Malmöhus (Nilsson 1974).Since the variations in secchi disc transparency in six of the seven lakes only amounted to 35 cm and there is little investigation material,it was not considered appropriate to present any correlations between in situ measurment and DGL.The reliability of the secchi disc transparency values can also be questioned as the measurements were taken in only one place in each lake,part of which were apparently very heterogenous concerning particle concentration and secchi disc transparency.Consequently it is uncertain to what extent the registrations carried out in situ were representative of the respective lakes.

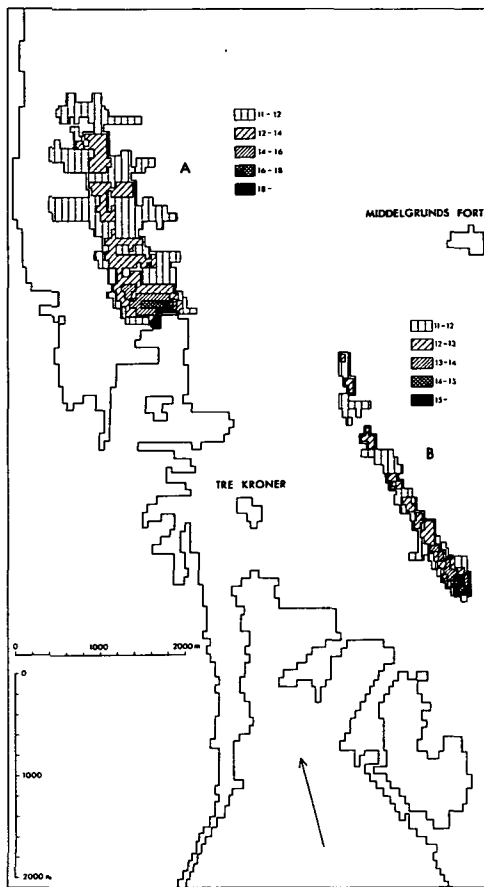
In spite of the small variations in secchi disc transparency between the lakes in question,it is evident from the results obtained that very small differences in water quality can be detected by analysis of LANDSAT digital data. The results also suggest possibilities of distinguishing chlorophyllous water from water whose secchi disc transparency is above all dependent on suspensions of non-chlorophyllous matter.In addition,certain conclusions can be drawn about quality conditions at different depths of water at the same time as a measure of the patchiness of different water masses can be obtained regarding transparency and particle concentration.

In order to determine the statistical relations between different types of spectral functions and water qualities the collection of ground truth data from about 200 lakes for comparision with satellite data is in progress.For further investigations laboratory analyses by spectrometer are probably necessary in order to determine how the spectral properties of water vary with different algae species and with different concentrations and to what extent minerogenic suspensions can affect the results.

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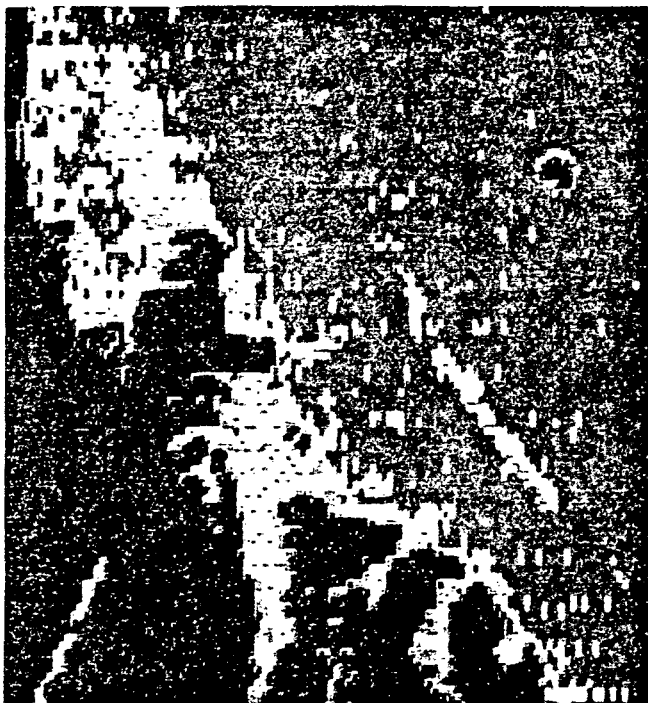
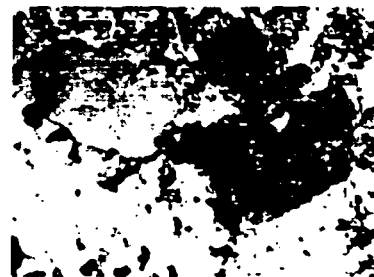


FIG.4. COPENHAGEN WASTE PLUMES. The extension and relative concentration distribution of the Copenhagen pollution plumes generated by Ink Jet Plotter (MSS 5 and MSS 7, 27/8-73). Green=land. The image is filtered for the LANDSAT line scanner noise.



MSS 6

FIG.6. LAKES RINGSJÖARNA. Calcomp plot in MSS 4 and MSS 6.



FIG.5. LAKES RINGSJÖARNA, generated by Ink Jet Plotter in MSS 4 and MSS 7 (27/8-73). The image is filtered for the LANDSAT line scanner noise. Green=land, dark blue=highest transparency and lowest particle (phytoplankton) concentration. Dark red=lowest transparency and highest particle concentration.

The left lake is Västra Ringsjön, the right lake is Östra Ringsjön and the upper-most part of Östra Ringsjön is Lake Sätöftasjön.

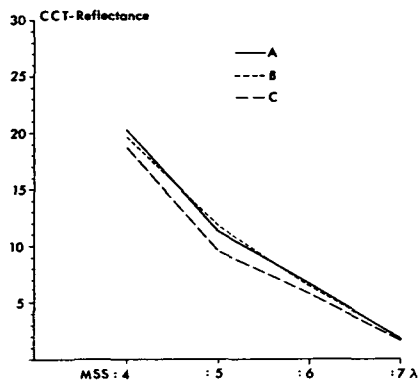


FIG.7.a. SPECTRAL DIAGRAM for the pollution plumes A and B and for "clean" water off Copenhagen.

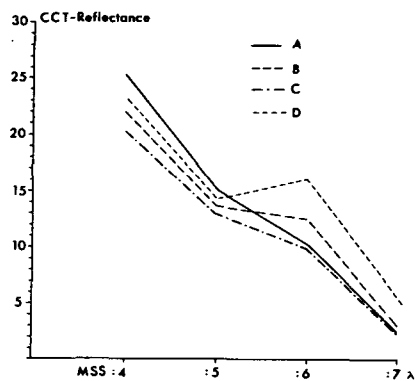


FIG.7.b. SPECTRAL DIAGRAM for the Lakes Västra Ringsjön (A), Östra Ringsjön (B), Sätöftasjön (C) and an algae strake in Lake Östra Ringsjön (D).

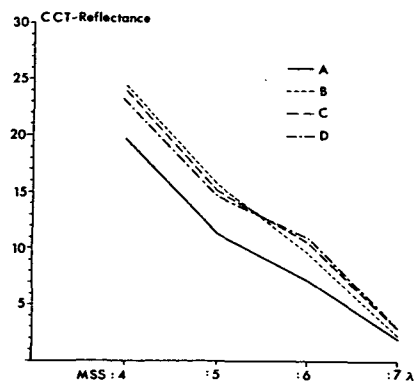


FIG.7.c. SPECTRAL DIAGRAM for the Lakes NW Ystad. A=Krageholmssjön, B=Ellestadsjön, C=Snogeholmssjön and D=Sövdesjön.

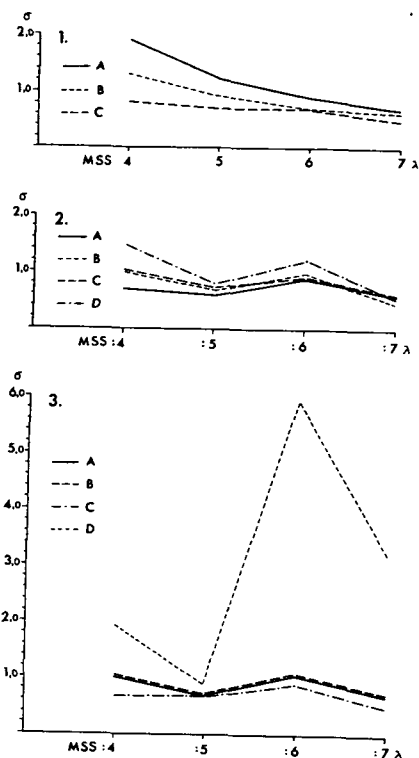


FIG.8. SPECTRAL FUNCTIONS regarding standard deviations of digital grey-tone levels. (1) The Copenhagen area, (2) The Lakes NW Ystad, (3) Lakes Ringsjöarna. The functions are named in the same way as in Fig. 7a-7c.

INDICATORS OF INTERNATIONAL REMOTE SENSING ACTIVITIES

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ABSTRACT

METRICS, INC. recently completed a survey to determine the extent of worldwide remote sensing activities, including the use of satellite and high/medium altitude aircraft data. Data were obtained from numerous individuals and organizations with international remote sensing responsibilities.

Nine indicators were selected to evaluate the nature and scope of remote sensing activities in each country. These indicators ranged from attendance at remote sensing workshops and training courses through the spectrum of remote sensing activities to the establishment of earth resources satellite ground stations and plans for the launch of earth resources satellites. Each country was then classified into one of three categories (beginning, moderate/intermediate, or advanced) according to the ranking of its indicators.

Results of the survey indicate that more than 110 countries are involved in some form of remote sensing activity. Also, more than twenty international organizations are actively promoting the use of remote sensing data around the world. Furthermore, this technology constitutes a rapidly increasing component of environmental, land use, and natural resources investigations in many countries, and most of these countries rely on the Landsat satellites for a major portion of their data.

1. INTRODUCTION

This paper presents the results of a comprehensive data collection effort and evaluation concerning international remote sensing activities. The purpose of the project is to determine the extent of use of remote sensing data by each country. Remote sensing activities include use of satellite and high/medium altitude aircraft data for mapping, resource investigations, and environmental studies. The scope of the survey is the entire world, but includes only U.S. activities which involve a joint research project or cooperative venture with another country. Specific objectives of the survey are:

- * A country-by-country evaluation of remote sensing activities for all countries known to be actively involved in remote sensing;
- * Classification of each country into one of three categories according to the nature and extent of remote sensing data use; and
- * Evaluation of the remote sensing activities of international organizations.

To obtain the needed data, numerous individuals and organizations with international remote sensing responsibilities were contacted. Data were obtained from such organizations as NASA, USGS, the United Nations, the Canada Centre for Remote Sensing, several international development agencies, and a number of other organizations and individuals from around the world.

2. INDICATORS OF REMOTE SENSING ACTIVITIES

Nine indicators were chosen to use in measuring the nature and extent of remote sensing activities in each country. These indicators were selected to measure all levels of remote sensing activities from the earliest stages when training activities predominate through the most advanced levels of remote sensing technology including establishing satellite ground receiving stations and data distribution/analysis centers. The indicators are listed and discussed in the approximate order in which a number of countries have progressed in the use of remote sensing.

1. Attendance of personnel at remote sensing workshops, training courses, and symposia.
2. Hosting/co-sponsoring workshops, training courses, and symposia sponsored by international development agencies and/or countries with advanced remote sensing programs.
3. Receipt of international assistance in the use of remote sensing technology such as joint remote sensing projects or development projects with a remote sensing component.
4. Participation in the Landsat and/or Skylab research programs.
5. Active participation in regional cooperative remote sensing activities.
6. Existence of a national remote sensing agency and/or well developed remote sensing infrastructure.
7. Provision of international assistance in the use of remote sensing technology.
8. Existence of, or firm plans for, an earth resources satellite ground station.
9. Plans for development and launch of an earth resources satellite.

Each of these indicators is explained in more detail in the following paragraphs.

Attendance at Workshops, etc. Generally this is the first evidence of a country's interest in remote sensing activities. One or more individuals from the country will attend a workshop, training course, or symposium concerned primarily with remote sensing. Sponsorship of the individual's travel and fees might be by his government or an international aid program or a combination of the two. Generally, these attendees are high ranking government officials with planning/resource responsibilities.

Hosting/Co-Sponsoring Workshops, etc. After a country becomes seriously interested in the utilization of remote sensing data for its planning and resource studies, hosting and/or co-sponsorship of an international workshop or training course is a possibility. There are numerous recent examples of such workshops, sponsored by an international development agency, with attendees from the host country and several surrounding countries.

Receipt of International Assistance. Once a particular country has determined the usefulness of remote sensing techniques for its own purposes, it

is not unusual for it to apply to an international development agency for assistance. This is particularly true among the developing countries which often lack the financial and technical resources to start their own program without external support and assistance. Many resource development projects having a remote sensing component are currently underway around the world.

Participation in Landsat/Skylab Research Programs. This is an important indicator of interest in remote sensing activities, but it tends to overlap the first three indicators, at least in time, for many countries. Since funds for participation in NASA's Landsat and Skylab investigation programs are supplied either by the individual country or by an international development organization, it represents a financial commitment of a portion of the resources of that country to the use of remote sensing data. Hence this is an important step in the evolution of a country's remote sensing activities.

Active Participation in Regional Cooperative Activities. A further indication of interest in utilizing remote sensing data in an operational environment is regional cooperation. The cooperation may be solely among the neighboring countries or it may be joint cooperation with another country (e.g., the U.S. or Canada) or with an international development organization. This indicator is differentiated from the receipt of international assistance by extensive, active participation of high level technical and resource personnel from each of the cooperating countries.

Existence of a National Remote Sensing Agency. The formal establishment or designation of a national remote sensing agency carries significant implications for the future of remote sensing within a particular country. Establishment of such an agency will either formalize the existing remote sensing infrastructure or it will likely serve as the catalyst for the formation of a remote sensing infrastructure within the country. In either case, it tends to promote strongly the utilization of remote sensing technology. This step is frequently combined with the establishment of a national training center or a technical assistance program.

Provision of International Assistance. Providing assistance to other countries is generally a sign of a relatively advanced, and often an operational, remote sensing program within the country which provides the assistance. There are numerous recent examples of developed countries with advanced remote sensing programs cooperating with international development agencies in holding seminars, short courses, and symposia, in various parts of the world. In other instances technical assistance is provided directly to another country or to several countries in carrying out remote sensing projects of local or regional importance.

Existence of/Plans for an Earth Resources Satellite Ground Station. This indicates a substantial financial commitment to an on-going, operational remote sensing program by a country or regional association of countries. It also generally indicates substantial experience with and facilities for the analysis and interpretation of photographic and digital remote sensing data. An expenditure of this magnitude is also indicative of long-range plans for the use of satellite remote sensing data.

Plans for Earth Resources Satellite. At the present time, only a few countries (e.g., United States and USSR) have definite plans for the development and launch of earth resources satellites. However, there is a rapidly growing list of countries which are formulating plans for the launch of their own satellite or are cooperating with other countries in planning such a satellite.

The above list of indicators is not perfect by any means. They probably could have been ordered differently, or additional indicators could have been selected, or perhaps the indicators selected could have been further subdivided and refined. However, the nine indicators discussed are the ones selected for evaluation of the remote sensing activities of the countries involved. Use of these indicators in the evaluation process is discussed in detail below.

3. METHODOLOGY FOR EVALUATING REMOTE SENSING ACTIVITIES

Several hundred references as well as personal contacts from around the world were consulted in compiling this paper. The approach was to collect all available documentation and information relating to international remote sensing activities. Data from several sources were often merged to get a complete picture of remote sensing activities within a particular country or organization.

A relatively simple scheme for evaluating the extent of remote sensing activities is employed. It involves a determination of the highest level of activity (according to the ranking of indicators as presented previously) that a particular country has attained. Each country is then classified into one of three categories: advanced remote sensing programs; moderate/intermediate levels of remote sensing activities; and remote sensing activities in early stages of development.

Countries which exhibit involvement in activity indicators one through three only are classified as being in the early stages of developing their remote sensing activities. Countries which participate in programs involving indicators four or five are classified as having moderate/intermediate levels of remote sensing activity. Finally, countries which demonstrate evidence of the characteristics inherent in indicators six through nine are classified as having advanced programs.

International organizations (or national organizations with international responsibilities) involved in remote sensing activities were not ranked according to the level of their activities. With respect to such organizations, the present effort was limited to cataloging all such organizations with current or planned remote sensing activities. Some of these organizations are very advanced in their use and/or transfer of remote sensing technology whereas others have only recently become involved in such activities or are in the early planning stages for these activities.

All organizations included in this listing belong to one of two categories: (1) international organizations composed of or chartered by several (or many) countries or (2) national (i.e., government) organizations which have international responsibilities. The United Nations is an example of the former type of organization whereas the United States Department of State/Agency for International Development is an example of the latter. Private (i.e., non-government) organizations and universities are excluded from the list.

4. RESULTS

Results of the survey indicate that many countries and organizations are formulating operational remote sensing programs without the extended research phase which has preceded most operational remote sensing activities in the United States. Furthermore, many developing countries are using remote sensing data in a wider range of problem areas than those of the more developed countries.

The countries involved in remote sensing are categorized according to the extent of their activities in Table I. The international development organizations identified as users/promoters of remote sensing technology are identified in Table II.

Among the statistical results of the survey are the following:

- * More than 110 countries are participating in some form of remote sensing activity.
- * More than 600 organizations worldwide are involved in remote sensing activities.
- * More than 75 countries have utilized Landsat data in various types of resource and mapping studies.

- * More than 20 countries and/or international organizations have existing or proposed ground stations capable of receiving Landsat data.
- * More than 30 countries are classified as having advanced remote sensing programs.
- * More than 20 organizations are actively promoting the use of remote sensing data in less developed countries or are using this technology in conjunction with existing development projects.

5. DISCUSSION

There are some limitations to the scheme employed above. In particular, the dividing lines between categories are not sharp. Furthermore, it is possible that the sequence presented here simply does not represent the evolution of remote sensing activities in some countries. Nevertheless, it serves as a common point of reference for classifying the various activities of each country, and it parallels the development of remote sensing activities actually observed in a number of countries.

6. CONCLUSIONS

From extensive analyses of international remote sensing activities, METRICS, INC. concludes that this technology constitutes a rapidly increasing component of environmental, land use, and natural resources investigations in many countries throughout the world. In addition, there is a substantial demand for remote sensing training in those countries which have some, but as yet fairly limited, remote sensing activities. Finally, satellite data is the major remote sensing data source for the majority of the countries in the world.

7. ACKNOWLEDGMENTS

The author would like to thank the many organizations and individuals who supplied data for this effort. Without their assistance this summary could not have been so complete. The author regrets any errors in classification or omissions. These are, of course, unintentional. Additions and/or corrections to these data would be appreciated so that future efforts of this type might be as complete and accurate as possible.

TABLE I. CLASSIFICATION OF REMOTE SENSING ACTIVITIES

<u>Beginning</u>	<u>Moderate/Intermediate</u>	<u>Advanced</u>
Afghanistan	Austria	Argentina
Algeria	Botswana	Australia
Benin	Bulgaria	Bangladesh
Burma	Burundi	Belgium
Cameroon	Central African Republic	Bolivia
China (Formosa)	Chad	Brazil
Congo	Colombia	Canada
Cyprus	Costa Rica	Chile
	Ecuador	Czechoslovakia
Dominican Republic	Ethiopia	Denmark
El Salvador	Gabon	Egypt
Fiji	Greece	Finland
Gambia	Guatemala	France
Ghana	Guinea	Federal Republic of Germany
Guyana	Iceland	India
Honduras	Israel	Indonesia
Iraq	Ivory Coast	Iran
Jamaica	Kenya	Italy
Jordan	Korea (Republic of)	Japan
Laos	Kuwait	Mexico
Liberia	Lesotho	Netherlands
Madagascar	Libyan Arab Republic	Nigeria
Nepal	Malaysia	Norway
Nicaragua	Malawi	Pakistan
Panama	Mali	Philippines
Portugal	Mauritania	Romania
Qatar	Morocco	Spain
Rhodesia	New Zealand	Sweden
Rwanda	Niger	Switzerland
Saudi Arabia	Peru	Thailand
Sierra Leone	Senegal	USSR
Somalia	South Africa	United Kingdom
Syrian Arab Republic	Sri Lanka	United States
Togo	Sudan	Upper Volta
Tunisia	Swaziland	Zaire
Uruguay	Tanzania (United Republic of)	
Yemen	Turkey	
Yugoslavia	Uganda	
Zambia	Venezuela	

TABLE II. ORGANIZATIONS INVOLVED IN
INTERNATIONAL REMOTE SENSING ACTIVITIES

Canada Centre for Remote Sensing
Canada International Development Agency
Center for Natural Resources, Energy and Transport
Central Treaty Organization
Economic and Social Commission for Asia and the Pacific
Economic Commission for Africa
Economic Commission for Latin America
Economic Commission for Western Asia
European Space Agency
Food and Agriculture Organization
Inter-American Development Bank
International Bank for Reconstruction and Development (World Bank)
Liptako-Gourma Authority
National Aeronautics and Space Administration
Swedish International Development Agency
United Nations Development Programme
United Nations Disaster Relief Organization
United Nations Educational, Scientific and Cultural Organization
United Nations Environment Programme
United States Department of State/Agency for International Development
United States Geological Survey
World Health Organization
World Meteorological Organization

QUANTITATIVE EVALUATION OF WATER BODIES DYNAMIC
BY MEANS OF THERMAL INFRARED AND MULTISPECTRAL
SURVEYS ON THE VENETIAN LAGOON

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ABSTRACT

This work which is a part of the research effectuated to save Venice and its lagoon, was carried out by remote sensing techniques.

The investigated area is the 'Bocca di Porto di Lido', entrance mouth to the Lido Port which is the most important inlet directly influencing the Historical Center of Venice and the behaviour of an half of the lagoon area.

The aim of this work is to perform a quantitative study of the changing of some parameters with no conventional oceanographic method.

Five surveys (whose repetition rate was one hour) employing a two-channel Daedalus Infrared Scanner and multispectral photography were performed for a complete investigation of spring waning tide.

By means of an electrical analogic technique the thermal signal was analyzed following the shift of a surface involving two fixed temperature during the tide.

This kind of investigation, repeated for each survey, allowed us to calculate the velocity of water mass under the hypothesis that the lateral thermal conductivity was practically negligible. The multispectral photography investigation allowed the discrimination between the different kinds of suspended matter (mainly organic and non-organic).

The sea-thruth on surface was captured by means of local probes with continuous recording of temperature, salinity, sediment transport and ebb stream velocity.

Some considerations about the behaviour of the front of an outgoing "plume" in order to understand the relationship between the two water masses, coming from the northern and Lido lagoonal basins were carried out; this investigation was conducted in order to correlate the bottom topography with the dynamic appearance on the sea surface.

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1. INTRODUCTION AND OBJECT OF STUDY

The Special Law, for safeguarding Venice, stipulated the terms and the conditions for any intervention concerning the regulation of the exchange of internal waters with the sea. The principal provision considers the reduction of the opening of the port, but since there are still questionable doubts as to the effects of such an act, it was resolved to execute a series of different surveys.

By employing boats various section of the inlet of the Port of Lido were traced to obtain direct measurements of the current velocity and the principal chemical-physical parameters. All the data were compiled to meet the precise requirements necessary for the formulation and functioning of mathematical and physical models.

A well equipped airborne remote sensing unit, utilized to survey the sea-surface "state" made it possible to integrate the direct measurements to the overall studied area.

Moreover the time-interval surveys accurately described the dynamic phenomena occurring between the lagoon and the sea in terms of their dimension and their evolution.

2. INVESTIGATED AREA

The area under investigation is the Lido inlet (Fig.1), the largest of the three lagoonal entrances (Lido, Malamocco and Chioggia inlets).

Almost 900m wide this hydraulic junction sustains approximately and inflow and outflow of more than one million cubic meters of water for every tidal cycle transporting the waters of Sant Andrea, Sant'Erasmo and Treporti respectively, the latter feeds the entire northern basin.

The depth ranges between 2 to 17m and the greatest depth is found in the south western part of the canal.

For a complete coverage of the area the aerial survey was performed from a constant altitude of 1500 m a.s.l. on the axis of the inlet in a south-east and north-west direction.

A total of five flights, each at one hour interval starting at 11,50 a.m. provided the information enabling a complete study of a syzygial waning tide evolution (Fig.2 the plume flowing between the jetties) (Fig.1 dotted square demarcates the investigated area; the arrow indicates the point where direct measurements were taken).

3. METHODS USED

To study the above mentioned phenomena five surveys were simultaneously run in the visible bands (blue, green and red) and in two thermal infrared bands.

Photographs were taken with a "cluster" of three electric Hassblad cameras equipped with Distagon 40mm lenses.

The following film-filter combination were used:

- a) B&W Kodak Plus-x film and a 47 Wratten filter (blue band)
- b) " " " " " " 58 " " (green band)
- c) " " " " " " 25 " " (red band)

In the thermal infrared bands a Daedalus scanner model I230 was used.

This instrument provides quantitative data and can be considered as a precise scanning radiometer. In fact, it is provided with two built-in black bodies at constant temperature adjustable in such a way that is makes possible to calibrate the electrical signal.

This is true only if atmospheric absorption is very low or negligible; however, even if atmospheric absorption is considerable this instrument can be employed looking at relative and not absolute measurements.

Very often, in fact as in our case, it is not so important to measure the absolute black-body temperature of the surface as it is to evaluate the differences of black-body temperature between one point and another. Then, since we can suppose with a good approximation that the atmospheric absorption is constant during the test time (a few minutes for each survey) and over the investigated area (3 km) no correction is needed for atmospheric effects.

Two bands of the thermal infrared regions were used and they are as follows:

- a) 4.5-5.5 micron with InSb detector
- b) 9-11 micron with HgCdTe detector

In our case only the 9-II micron band was used since it is the best for the range of temperature under consideration.

Direct measures of "sea-truth" were effectuated from a boat anchored at short distance off of the southern jetty within the entrance of the Port of Lido (arrow in Fig.1).

The parameters surveyed, during the entire waning tide, were as follows: temperature, salinity, ebb stream, velocity and turbidity.

The temperature and velocity data were required for a direct comparison of the values obtained from the thermographic analysis.

Fig. 3 : a) thermography from first flight

b) "slicing" at 6 levels

Fig. 4 : graphic recording of principal chemical-physical parameters measured directly "in situ".

During a time span of seven hours, the turbidity and velocity parameters were continuously recorded while temperature and salinity were measured every 15 minutes. Measurements were always made maintaining the probes at the same depth and a minimum distance from the water surface.

Temperature and salinity were measured using a MC5 Electric Switchgear probe with a sensitivity of 0.1 °C and 10 ppm. For turbidity, a Parteck solid suspended monitor with a HP 20 probe based on the principle of differential absorption of light was used with a sensitivity of 2 ppm and a full scale calibrate to 25 ppm.

Ebb tide velocity was surveyed with a unidirectional correntometer model B/8 of the Marina Adviser, with a scale of 10-15 knots and a sensitivity of 0.1 knots.

4. CALCULATION OF SURFACE VELOCITIES

On the possibility of measuring the average waning tide velocity at the sea surface we utilized the space covered by a front of an area at a constant ΔT between one flight and another at one hour interval.

Assuming that thermal exchange of air-water due to the conduction is negligible for this type of calculation; remembering that the ΔT between air and water is minimum the radiation is neglected too.

Of the 5 available thermographs from the five flights were examined only the third and fourth one.

The front of the isotherm area under investigation was situated in the proximity of a point where the sea truth was captured in order to confirm the validity of the method.

The thermography from the third flight (13,50 p.m.) is represented in Fig.5a, while in Fig.5b, the "slicing" is shown where appears an area involving a ΔT .

On Fig. 6a, the thermography from the 4th flight (14,50 p.m.) is represented and in Fig.6b the "slicing" of the same ΔT precedently considered.

Fig.7 shows a comparison map of the isothermal area boundaries obtained from the two preceding "slicings". On this map, it is shown that the front of the isotherm are advanced in an hour 2200 m corresponding to 1.2 knots.

The velocity measurement carried out at the point indicated by the arrow, in Fig.1, gives 1.4 knots with a difference of 0.2 knots i.e. 15%.

Such a difference, also present in the errors of the measurements of the traditional oceanographic instruments, is to be attributed to the presence of average wind blowing from the S-E in an opposite direction to the water movement at a speed of about 14 km/hour inhibiting the surface outflow.

Regarding the circulation of the water masses coming from the northern basin it was'nt possible to take reliable measurements since the path of the water current undergoes an abrupt change, as shall be seen later on in the hydrodynamic interpretation, so that it is physically impossible to follow the same isotherm level during one hour.

5. DYNAMIC INTERPRETATION OF THE PHENOMENON

Explaining movements of the surface currents is extremely easy with the aid of thermographies. In fact, it is enough to outline the various paths of the isotherm areas to automatically have

a map of the surface's current circulation, using temperature as a tracer. It is more difficult, even if feasible, to describe the currents paths under the sea surface, taking into account the bathymetry and what occurs at the surface.

In this case, it is just the matter of a precise and accurate interpretation of a physical phenomenon of which the boundary conditions are known.

Even being significant the results of all the flights, it seemed more interesting, for the study of dynamics, those where the velocity of the two water masses (coming from the south and north respectively) is maximum and that happen in the flights 3 and 4 as shown in Fig.7. In Fig.8, an outline is drawn which represents the probable paths of the two currents, denominated as (N) and (S) before entering into the canal, and then up to the mixing as they are apparent from the surface black body temperatures. On this phase, we have the advantage that (N) and (S) have two very different temperatures ($\Delta T = 2.5^{\circ}\text{C}$) so that they are well distinguishable one from the other.

Above all, our attention is focused on the A and B points (see Fig.8).

At point A, a thermal discontinuity is so strong to be only explained by hydraulic considerations that is current (N) flows under current (S).

At point B, a water mass colder than the surrounding water is detected at the surface which could float only if its density were less than that around it, that is to say a very low salinity.

The above described dynamic behaviour is confirmed taking into account a bathymetric profile shown in Fig.10, where it is very easy to observe a thermocline (arrow) testifying the existence of two water masses with two different physical characteristics, floating in the foreseen location.

As we can see in Fig.8 and 9, we find at point C, just slightly after the immersion of (N) under (S), a lowering of the bottom unjustifiable if it was not for the erosion associated with current (N).

Lastly, we can see that the geometry of the bathymetry near the two light houses at the end of the jetties are somewhat diverse. It could even be in this case an effect of accelerated erosion induced by current (N) that therefore affects point (D), in comparison to that relative to point E.

6. CONCLUSION AND FINAL CONSIDERATIONS

As already mentioned in the introduction, this work was executed by using an unusual survey technique for the circulation data and as shown from the results presented this kind of approach seems particularly good for this type of phenomena.

The positive and negative aspects of this technique are briefly summarized as:

- 1) synopticity of the survey: it is evident that in no way ground measurements even plentiful can reach a synthesis so complete from only one survey
- 2) precision of measurements: absolute temperature measurements are not allowed (whose interest is relatively scarce). Relative measurements are possible with a precision up to at least 0.2°C which seems to be the limit even for the traditional thermometers
- 3) possibility of extended investigation : when the aircraft is in flight, the cost increment of an investigation in a near zone is extremely low
- 4) possibility of various investigations: for the same reason just stated above, it is cheaper to load the plane with as many instruments as possible, thereby gathering the maximum data with the minimum of cost
- 5) impossibility of using the thermal infrared bands to investigate underneath the surface: this is due to the nature of the electromagnetic radiation in that wavelength
- 6) the use of temperature as a tracer is feasible, but we can't (for obvious thermal exchanges with the surroundings) study from the air extremely large areas. This will be possible when the thermal sensors on board the satellites will have a thermal and geometric resolution useful for these scopes
- 6) for the following investigations it could be good to effectuate for every scheduled survey

at least two flights over the same area a few minutes apart, to catch small but significant movements of the water masses

- 7) taking into account the wind effect it is advisable that these surveys has to be carried out in the absence of wind or at least when blowing at a constant speed as in our case.

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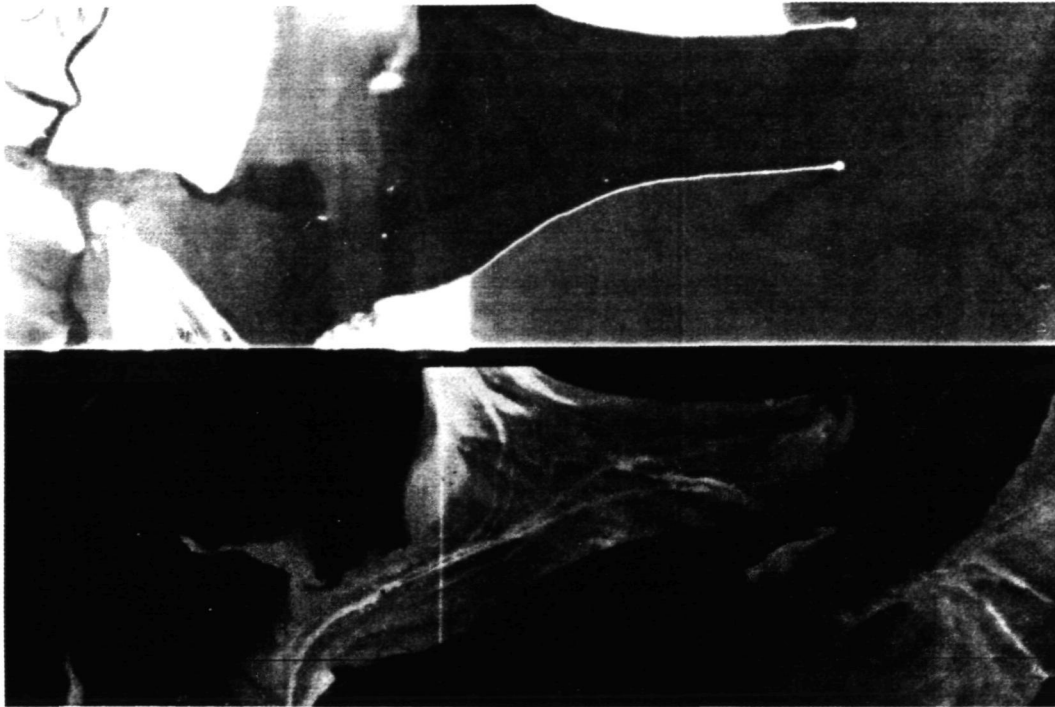


Fig.3. Thermography of the first flight (up)
Level slicing of the previous thermography (down).

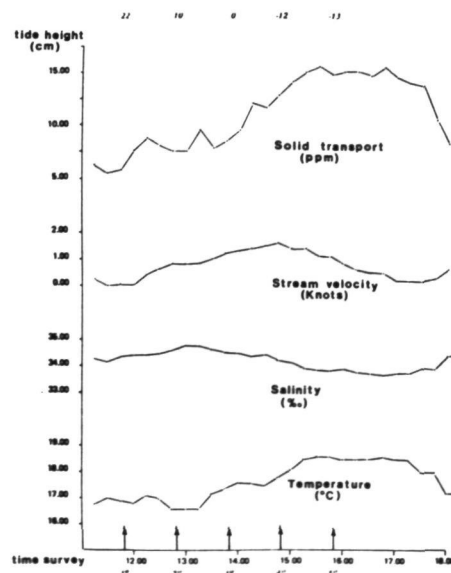


Fig.4. The four parameters recorded "in situ"
(see arrow in fig. 1).

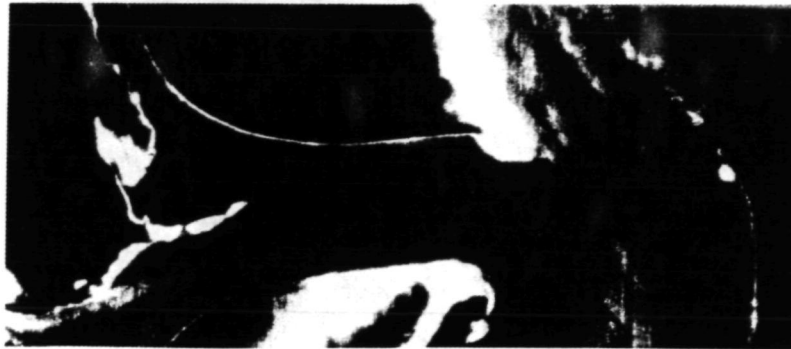
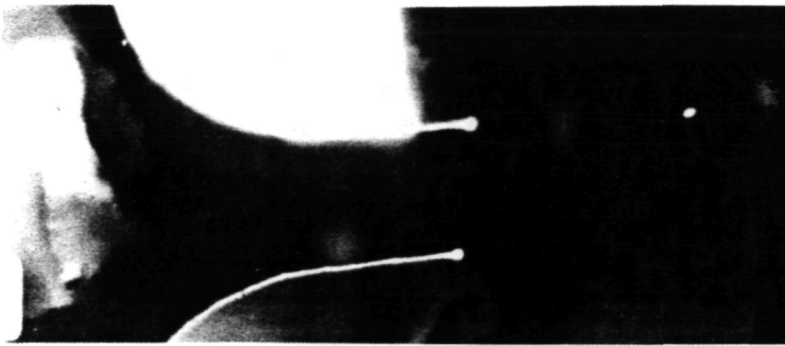


Fig. 5. Thermography of the 3rd flight (up).
The level slicing used for the velocity calculation.(down)

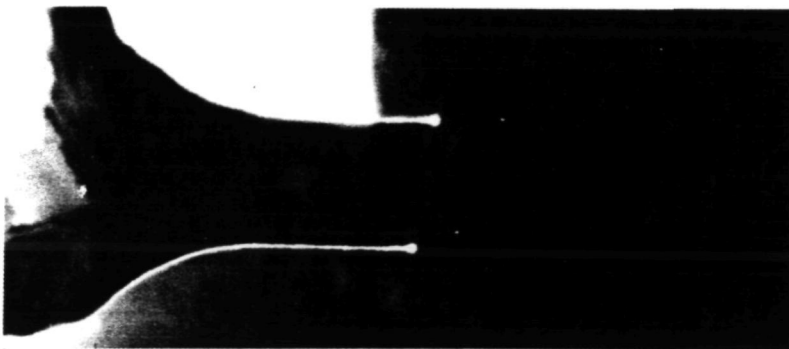


Fig. 6. Thermography of the 4th flight (up)
The level slicing used for the velocity calculation (down)

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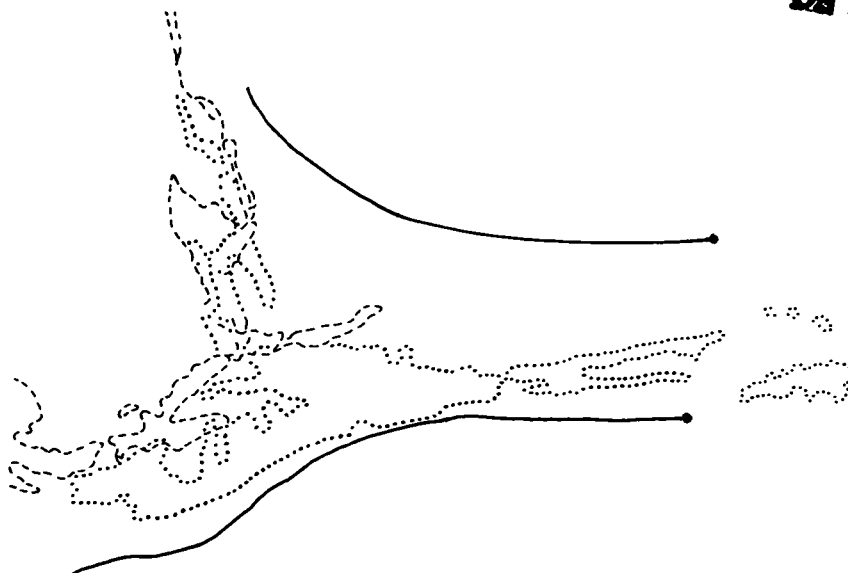


Fig. 7. Comparison between the boundaries of the isolevels of the 3rd and the 4th (dotted) surveys.

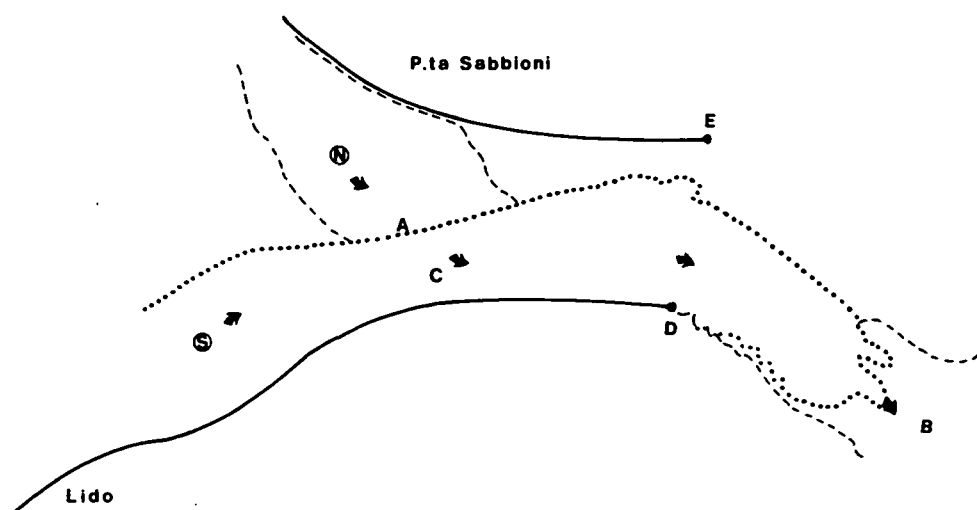


Fig. 8. Map of the dynamics of the two water bodies.

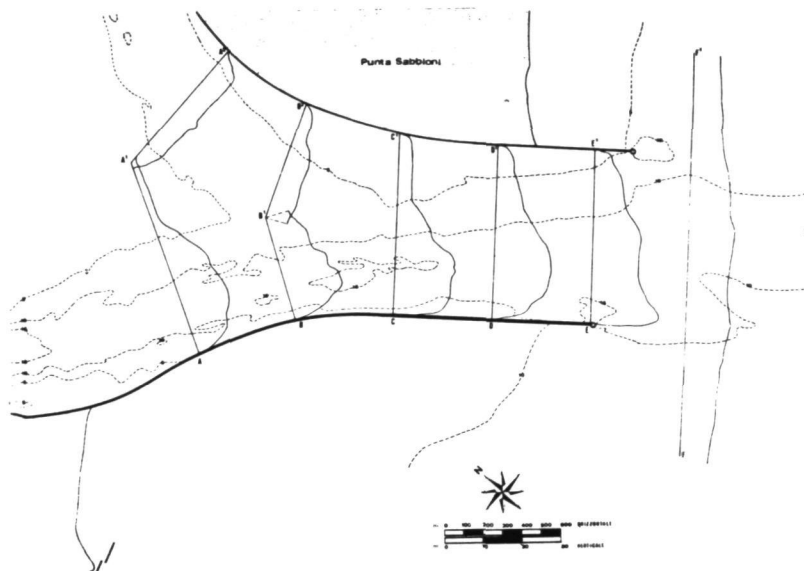


Fig. 9. Cross bathymetric prophiles of the inlet.



Fig. 10. On-axis bathymetric sonar survey of the southern part of the inlet.

VIZIR - THE S.E.P. HIGH RESOLUTION LASER BEAM RECORDER

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Vernon, France1. INTRODUCTION

In terms of Satellite System, there is a common tendency to think that all of the engineering and technical problems turn to the level of the onboard equipment. Although this is true in most, not to say in the majority, of the cases, there is, however, a number of equipment items for ground based stations, that raise some intricate problems ; among such equipment items, can be mentioned the image reconstruction systems on photographic films that are used in the ground based receiving stations, of the meteorological data transmitted by satellites such as the S. M. S., for instance.

I have much pleasure in having to tell you about a high performance image reconstruction unit, for which a number of delicate issues had to be solved by use of advanced techniques... sometime with a great deal of novelty.

The problem submitted to us was quite simple in its wording :

"How to reconstruct, at the ground, in real time, the image data transmitted from the S. M. S. Satellite in its various modes, while keeping the very high resolution of the image scanned by the onboard sensors ?".

The answer to be given was just as simple : "the only requirement is to design and build an image reconstruction unit which suits to the problem".

In order to make the account less anonymous, I must tell you that the Agency that raised the problem was the French National Meteorology, and the company who solved it ; was SEP (Société Européenne de Propulsion) by proposing the VIZIR, a "laser beam recorder" I am now going to describe to you further.

2. FUNCTIONS OF THE VIZIR IN A METEOROLOGICAL DATA RECEIVING STATION

The Wallops Station retransmits every fifteen minutes a visible image and a infrared image previously scanned by the sensors of the S. M. S/A satellite. The receiving station of the French National Meteorology, located at LANNION, therefore receives data to be stored in an amount close to 250 million points. Various approaches may be envisaged for the storage, such a "digital archiving" on high density magnetic tapes, or "analog archiving" on photographic film.

For ground based stations of which the mission is to supply data for interpretation purposes, the analog approach is selected, enabling to have images available ; in the case of geostationary meteorological satellites a succession of images is available which allows quantifying the evolution with time of the overall events.

The VIZIR shall according be regarded as a means for high density archiving of the meteorological data on a photographic film. The data are stored on-line under a form accessible to interpretation. The VIZIR thus forms the final link of the receiving system of a ground station.

It may easily be understood that the major qualities such an equipment should feature are as follows :

- a modulation transfer function not impairing that of the scanning system onboard the satellite.

- a dynamic and a photometric resolution high enough to obtain a good signal-to-noise ratio.
- a high fidelity in the reproduction of the scale of grey on the image format and from one image to the other.
- a good reproducibility of the geometry of the image as well as from one image to the other to make superpositions possible (case of the colored compositions).

All such requirements are met with the VIZIR by use of most advanced techniques at the level of the subunits that constitute it.

3. PRINCIPE OF OPERATION AND MAIN PERFORMANCE LEVELS OF THE VIZIR

The VIZIR, is first of all, a laser beam recorder in operational service for more than two years now, in the sation of the C.E.M.S. (Space Meteorological Research Center) at Lannion. In order to understand its principle of operation, the following general ideas should be kept in mind : (fig. 1).

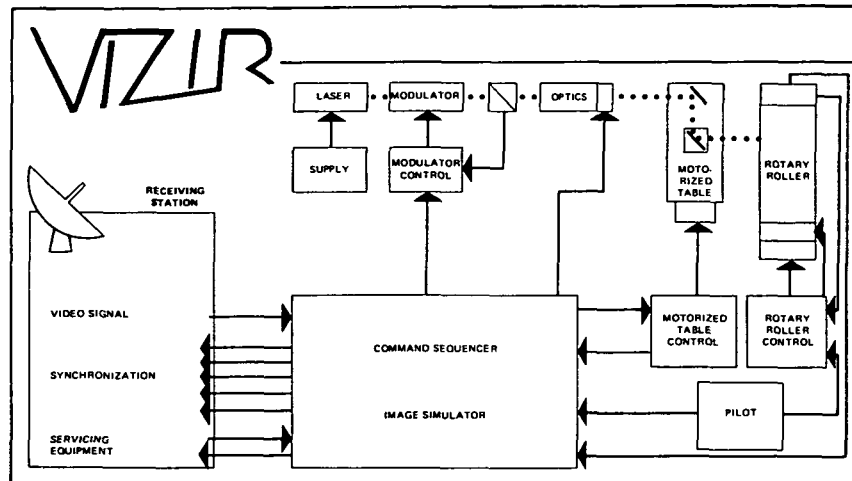


FIGURE 1 - GENERAL PRINCIPLE OF THE VIZIR

- the video-signal, proportional to the apparent ground luminance, controls a static light modulator of the electrooptical or acousticoptical type,
- the modulator placed behind a continuous beam laser acts as an optical filter the transparency of which varies at the rate of the modulation of the video-signal.
- the modulated light beam is focused on a photographic film ; the latter is placed on a rotating drum suspended on active magnetic bearings.
- a motorized table, with step by step feed motion, carries the focusing optical system ; this table travels parallel to the rotation axis of the drum at the rate of entry to the lines of the image.
- a continuous rotation of the drum at constant servolooped speed provides for point scanning.

Further, it is worth mentioning, that the equipment works in the asynchronous mode, which means that a low capacity buffer storage associated with the VIZIR mini-computer, acts as a regulator of the data rate between the output of the decoder and the input of the laser

beam recorder. This principle of operation avoids every difficulty of synchronization between the transmission and the reception.

According to the wise principle of "What can do more can do less", I shall just give the technical data of the VIZIR with the highest performance levels, therefore the one that was developed for the S. M. S. application (fig. 2).

Photographic Support	KODAK or 3 M film	Density levels	64 with $\Delta D = 0.037$
Image size	400 x 400 mm	Permanent distortion	$< 3.10^{-4}$
Number of lines	15,000	Random distortion	$< \pm 3.10^{-5}$
Spot diameter	27 microns	Gitter	$< \pm 0.610^{-5}$
Image reconstruction time	15 minutes	Video input signal	0-1 volt ; 300 KHZ

FIGURE 2 - MAIN CHARACTERISTICS OF THE VIZIR (SMS)

The large image size allows the users easy interpretation without having to resort to enlargement through a conventional process. Interest is arising in substituting the bath development type of film, by a heat development type of film providing faster access to the data and simplifying the operating procedure.

4. PRESENTATION AND OPERATING PROCEDURE OF THE VIZIR

The external presentation of the VIZIR features two separate subunits :

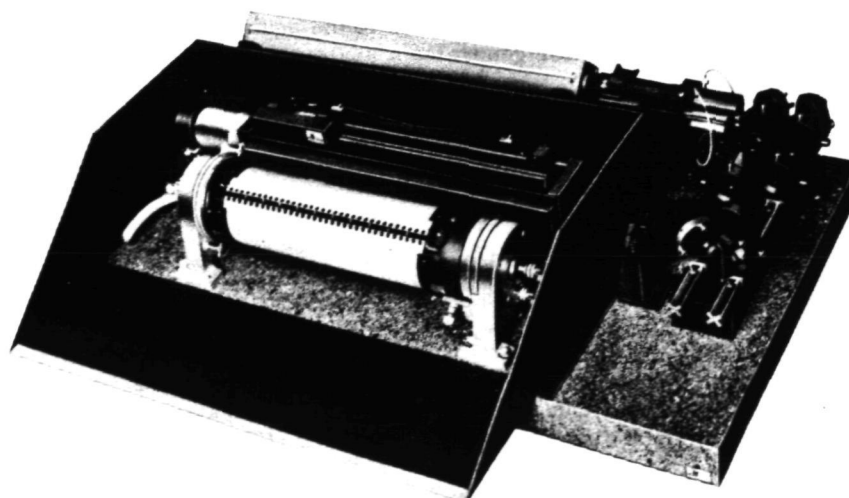


FIGURE 3 - ELECTRO-OPTICAL SUBUNIT OF THE VIZIR

- the first one, (fig. 3) referred to as the electrooptical subunit comprises the various optical components (laser, modulator, lenses) together with the mechanical components providing for line scanning (motorized table) and point scanning (rotating drum on magnetic bearings) ; all these components are arranged on a surface plate enabling strict maintaining of the optical alignments.

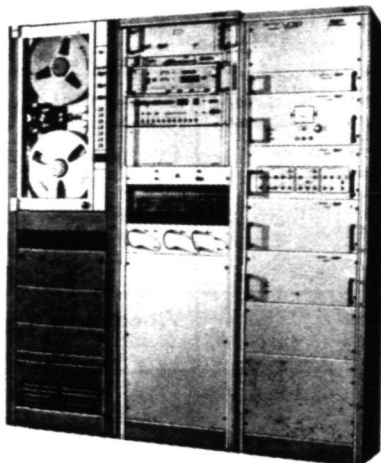


FIGURE 4 - ELECTRONIC SUBUNIT OF THE VIZIR

- the second one, (fig. 4) referred to as the electronic subunit, is in the form of a rack that comprises : the power supplies, the speed and suspension of the rotating drum servo-electronics, the mini-computer, a magnetic tape unit, eventually, and finally a control desk. It is from this desk that the operator controls the starting of the VIZIR and selects some of the options of the image reconstruction system such as the obtention of a negative or positive image, or a different resolution.

The two subunits are cable connected. They are generally used in association with an automatic film developing module.

The operator can monitor the performances of the equipment by means of a built-in test generator that internal simulator generates a scale of grey or a checker-board test pattern..

5. FIELDS OF APPLICATION OF THE VIZIR

Further to the reception of the image data transmitted from the S. M. S., it may be considered that the VIZIR is quite suited to :

- the reception of the data that will be transmitted from the European meteorological METEOSAT satellite. In that case, the resolution of the visible image (5,000 x 5,000 points) and of the infrared image (2,500 x 2,500 points) allows simultaneous and on line reconstruction of these two images on the format. This remark applies both to the reconstruction in the Central Station that will be located at Darmstadt and to the reconstruction in the Primary Data User Stations (PDUS).
- the reception of the data that are and will be transmitted from the U.S. satellites of the V. H. R. R. type. The same remark as above applies as regards the obtaining of simultaneous black and white and infrared images.

Prior to closing the list of the signal reconstruction configurations in ground stations, I would like to mention, that the VIZIR could readily be fitted to ERTS or LANDSAT receiving stations. (fig. 5).

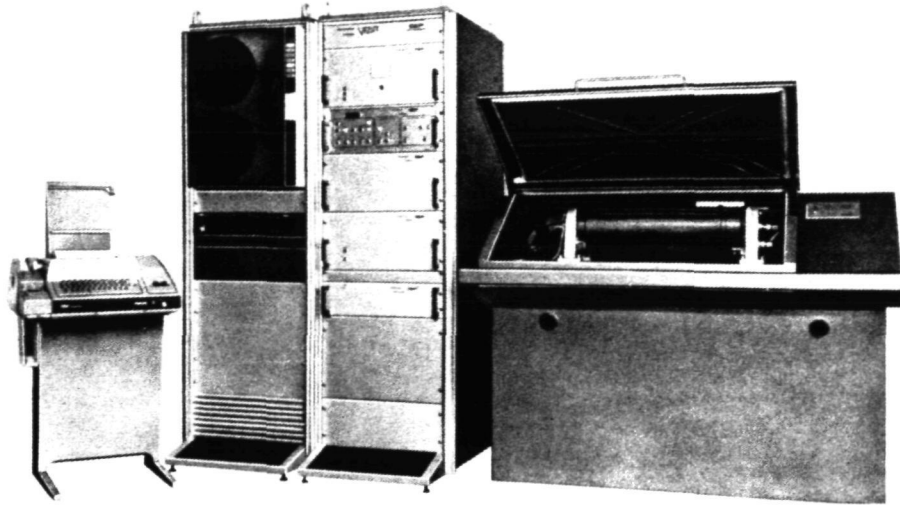


FIGURE 5 - IMAGE DISPLAY UNIT

Turning to other purposes, the applications of the high definition laser beam recorder to Digital Data Processing Centers are worth mentioning. After applying such or such calculation algorithms to image signals, a reconstruction on film is carried out with the object of subsequent data interpretation. For such type of OFF-LINE application a magnetic tape unit is added to the VIZIR, acting as the data source, together with a display console on color screen, according to the requirements, we call this grouping of equipment units an image display unit (Fig. 5). In France, "l'Institut Français du Pétrole" is already equipped with such a system. We are currently building another one for the Indian Space Organization : ISRO, and for the EURATOM CENTER of ISPRA (ITALIA).

6. CONCLUSION

Since a few years, the area of image reconstruction on photographic film has evolved towards a demand for higher and higher performance equipment. The present requirements in this area are likely to be exceeded within a short future and this is why SEP did not hesitate to develop a hardware making use of the most advanced techniques (laser, static light modulator, active magnetic bearings), enabling to effect the necessary extrapolations. Among such extrapolations there is ground to envisage, first of all, the direct reconstruction of colored photographs.

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TWO PHASE SAMPLING FOR WHEAT ACREAGE ESTIMATION¹

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ABSTRACT

A two phase Landsat-based sample allocation and wheat proportion estimation method was developed. This technique employs manual, Landsat full frame-based wheat or cultivated land proportion estimates from a large number of segments comprising a first sample phase to optimally allocate a smaller phase two sample of computer or manually processed segments. Application to the Kansas Southwest CRD for 1974 produced a wheat acreage estimate for that CRD within 2.42 percent of the USDA SRS-based estimate using a lower CRD inventory budget than for a simulated reference LACIE system. Factor of 2 or greater cost or precision improvements relative to the reference system were obtained.

1. INTRODUCTION

One of the most important aspects controlling the success of any inventory system is the sampling aggregation plan utilized. Substantial differences in final estimate precision, bias, and cost can occur depending on which sample design is selected. Moreover, the number of parameters (e.g. different crop acreages or yields) that can be estimated and the reporting level at which they are available are similarly affected by the design.

The advent of timely and relatively inexpensive remote sensing data has fostered new inventory sample design options and improved estimate performance possibilities. While progress has been made in this regard through the Large Area Crop Inventory Experiment (LACIE) and through smaller projects, current inventory performance capability falls significantly short of its present potential.

2. STUDY OBJECTIVE

In order to provide a relatively simple demonstration of crop inventory performance possibilities presently unexploited, a two phase Landsat-based sample allocation and wheat proportion estimation method was developed in this study. A simulated second year LACIE inventory system was used as a base for performance (precision, cost) comparison.

¹ Work supported by NASA Contract NAS 9-14565.

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The two phase technique employs manual, Landsat full frame-based wheat or cultivated land proportion estimates from a large number of segments comprising a first sample phase to optimally allocate a small phase two sample of computer or manually processed segments. Proportion estimates from each phase are then linked by regression or probability proportional to estimated size (ppes) estimators to provide wheat proportion estimates and standard errors by reporting unit.

3. SAMPLING AND MEASUREMENT METHODS

3.1 Information Requirements and Performance Goals

The information target for the inventory was defined to be wheat acreage sown (1973-74) expressed as a proportion of total land area for county and by U.S. Department of Agriculture (USDA) Crop Reporting District (CRD). Counties and CRD's were defined on a "pseudo" basis meaning that their boundaries were slightly modified so as to avoid splitting inventory sample segments.

Inventory precision control was set to achieve a wheat acreage estimate within five percent of the corresponding USDA estimate, 95 times out of 100 at the Crop Reporting District level. Budget and inventory throughput rate constraints were selected to be similar to those of the reference LACIE year two system.

Two Kansas CRD's were chosen to demonstrate the Landsat two phase sample technique in the winter wheat region. The first of these, the Kansas, Southwest CRD (11,865 mi²) occupies a predominantly semi-arid to sub-humid environment. The dominant small grain-related crop rotation in this water-limited area is summer fallow, wheat and sorghum. To provide a contrasting wheat distribution and appearance situation, the moister and more humid Central Crop Reporting District (8,968 mi²) was selected as the second Kansas inventory test area. Here moisture is no longer the dominant limiting agent and double cropping sequences often result. Field size is generally smaller, wheat density lower, and noncultivated range-grassland interfringes more extensively with cultivated areas within the Central CRD.

Inventory data was purposely limited to that available in the LACIE counterpart; namely Landsat full frame color infrared transparencies (not real-time), Landsat digital data for a small sample of five mile by six mile on-a-side segments, and ancillary crop calendar and cropping practice information. A more tailor-made domestic inventory system, not considered here, might also include aircraft and ground data for estimate and measurement calibration purposes.

3.2 Sample Design Specification

A stratified double sampling (i.e., two phase) design was selected to demonstrate the capability of remote sensing-aided systems to meet wheat proportion information requirements within the CRD performance constraints just described.

This design takes advantage of the relationship between a more expensive to measure variable Y (e.g., computer-based wheat proportion) and a corresponding less expensive to measure variable X (e.g., a rapid analyst estimate of sample segment wheat proportion). A relatively large first phase sample of observations on X may be used to efficiently allocate a much smaller sample of observations on Y. Similarly, the small sample of information on Y can be used to calibrate (to Y accuracy standards) the area-wide information on X. If the correlation between X and Y is sufficiently large, significant reductions in estimate (e.g., wheat proportion) variance and second phase (e.g., computer segment) sample size can result when compared with single phase sampling on Y alone.

Figure 1 illustrates the two phase sampling concept as applied to the wheat proportion estimation problem. The top layer in the figure was defined to represent a CRD-wide phase 1 sample frame composed of standard 5 x 6 mile (30 mi²) sample segments. A "data sandwich" consisting of several previous-to-crop-year Landsat transparencies was associated with the phase 1 sample frame. These color infrared transparencies were used by an image analyst to produce rapid and inexpensive wheat proportion estimates (variable X) for all sample segments.*

The resulting sample phase 1 proportion data were then used to minimize final crop estimate variance by stratifying the segment population into crop (in this case wheat or, alternatively, cultivated land) density strata. Thus, after tabulating a list of phase 1 data, a small phase 2 sample can be allocated within the phase 1 strata with either equal or variable probability. Stratified probability proportional to estimated size (of phase 1 wheat proportion) allocation was used to select sample phase 2 segments in this study. More accurate (Y variable) wheat proportion estimates were then made for each phase 2 segment selected by using multitemporal manual or machine-aided classification methods as illustrated by the lower layer in Figure 1.

3.3 Determination of Optimal Phase 2 Sample Size

The optimal second phase sample size, n, designed to minimize estimate variance for specified survey budget levels was determined via regression based optimal sampling rate formulas. These are presented and discussed in detail in Thomas and Hay.⁵ Optimal phase 2 sample size for each wheat density stratum is a function of the relative cost and correlation between phase 1 and phase 2 sample segment proportion measurements as well as the actual sample segment variability represented by the variance of Y. The latter quantity was estimated by the variance obtained from phase 2 sample segment wheat proportion data. For purposes of sample size determination, correlation between phase 1 and phase 2 proportion estimates was assumed to be 0.8 on the basis of preliminary tests.

Based on a detailed cost analysis⁵ it was determined that the cost ratio for unitemporal machine processing at phase 2 to analyst estimation at phase 1 was 170:1. If multirate manual classification of a small point sample was used instead at phase 2 then the cost ratio became 17:1.

A simulated LACIE system sample size was determined in order to define the total survey budgets available for the Kansas Southwest and Central CRD's. Crop year 1972-73 USDA statistics were used to give the proportion of wheat average sown, harvested, and produced in each CRD relative to the U.S. total.² Under an early LACIE assumption that 636 sample segments would be allocated to U.S. wheat regions, the total expected number of sample segments allocated to both CRD's was determined for each allocation factor.⁶ Cost per unitemporally processed computer segment was then multiplied times the sample size required under the acreage sown allocation assumption to give total available CRD survey budget. This budget represented that theoretically available to the reference LACIE system.

Given the crop reporting district budgets, phase 1 to 2 correlations and cost** ratios, and estimated phase 2 variances, optimal phase 2 sample sizes for the two phase sample with regression estimation were calculated. Sample selection was defined to be with replacement, pps, by stratum.

*Since all phase 1 units are sampled, the sample design applied here becomes regression sampling. However, the more general technique developed in this study can be applied when sampling less than the population size at phase 1.

**In order to be conservative relative to two phase sample system performance, a phase 2 to phase 1 ratio of 150:1 was assumed.

3.4 Specification of Measurement Procedures

Wheat or cultivated land percent estimates were obtained for phase 1 sample units by the first of two image analysis procedures developed in this study. The first image interpretation procedure allowed quick (approximately three minutes per segment including rest time) proportion estimates to be made from a base date Landsat full frame transparency. The base date was selected from a recent crop year date that gave maximum contrast between wheat versus other crop types. In the two Kansas CRD's examined, this base date occurred at or shortly after harvest. At this time, wheat fields appeared very white relative to all other cover categories.

When confusion situations were identified by reference to ancillary data concerning crop calendar and cropping practices as well as multirate interpretation of Landsat imagery, an additional one and rarely two dates of color infrared full frame data was referenced by the image analyst. Grain sorghum fields, not easily separable from wheat on the base date, represented an example of such a situation. Land use/soils association stratification on Landsat full frame data was found to provide a convenient means of coding circumstances in which wheat versus other confusion might occur.

A second image interpretation procedure served to provide phase 2 wheat proportion estimates. This technique was chosen to represent the best Landsat-based wheat proportion measurement capability available for phase 2 sample segments. Earlier tests had shown that this multitemporal image interpretation approach resulted in more accurate proportions than did corresponding unitemporal machine-aided classification. Ideally multitemporal machine processing should give results at least comparative to the manual method, and for this reason the machine cost figures were used for phase 2 sample size determination.*

The phase 2 wheat measurement procedure was to employ a systematic sample of 48 points over enlargements of phase 2 sample segments obtained from full frame transparencies. Enlargements were to CX120 "lantern slide" size representing a five to six times scale increase relative to the original 1:1,000,000 scale. Dates chosen for inclusion in this analysis included a representative having the least cloud cover, least noise, and most contrast between cover classes.

Wheat versus other classification were recorded on an acetate sheet covering a record photo for the given sample segment. In order to maximize wheat identification accuracy (correctly identifying wheat as wheat) and minimize commission error (classifying a sample point as wheat when it was not), other major non-wheat cover types and confusion crops were identified when possible. This additional identification task was designed to ensure a conscientious consideration of wheat alternatives by the photointerpreter.

3.5 Specification of Proportion Estimators

Two estimators were considered: stratified regression and stratified probability proportional to estimated size (ppes).^{1,3,4} Generally the linear regression estimator is used when the relationship between X (phase 1 proportion) and Y (phase 2 proportion) can potentially move far from the origin and when the variance of Y about the regression line (σ^2_e) remains approximately constant over the range of X. In this situation it is known as the best

*Original unitemporal machine processing costs were retained as opposed to substituting higher multitemporal costs. Again this assumption is conservative relative to two phase sample system performance.

linearly unbiased estimator (BLUE). When the relationship between X and Y is thought to pass close to the origin and σ^2_{ϵ} increases proportionally to X then ppes estimators are termed BLUE. This latter situation may occur especially in areas with high wheat density variability. In addition, ppes allocation may be used to drive second phase sample unit selection towards a greater proportion of "higher value" areas and still maintain unbiased estimation. For example, it may be desired to force computer segment selection to units tending to have higher wheat density or higher wheat variety spectral class mixture representation in order to maximize signature extension success.

4. SYSTEM EVALUATION: COST-EFFECTIVENESS ANALYSIS

A portion of the analysis involved a precision versus cost performance comparison between the double sampling system described in this study and the reference LACIE sampling system. This analysis was done to demonstrate the relative amount of improvement to be expected with inclusion of the full frame Landsat data in the system. The form of cost-effectiveness analysis used is known as a "system comparison study". It helps a decision-maker answer questions about how to achieve a given set of objectives at the least cost, or conversely, how to obtain the most effectiveness from a given set of resources.

5. RESULTS AND DISCUSSION

5.1 CRD and County Wheat Proportion Estimates:

Application of the two phase design to the Kansas Southwest CRD for 1974 produced a wheat acreage estimate for that CRD within 2.42 percent of the USDA SRS-based 1974 estimate using a lower CRD inventory budget than for the assumed referenced LACIE system. Table 1 presents the results for regression and probability proportioned to size (ppes) estimation for the Southwest CRD. Recall that both estimates are based on the same ppes draw of phase 2 sample segments. Consequently a comparison of the increased estimate precision available with ppes versus random within stratum selection could not be made aside from that resulting from the formulas themselves.

The regression estimator was used in a predictive manner to produce county estimates (see Table 2). County regression estimates for the Southwest CRD show a greater range of departure from their corresponding USDA-based values than the CRD level estimates. This situation is expected when sample allocation is optimized for the CRD as opposed to county level. Differences range from -6.66 percent in Stanton county to a low of 0.25 percent in Finney county to a 9.54 percent over-estimate in Ford county. The average difference, sign considered, was 0.18 percent (not statistically significant with the paired t-test). The average absolute difference, sign ignored, was 2.93 percent also found not to be statistically significant with the paired t-test.

The performance of both the regression and ppes estimators in the Kansas Central CRD was below that obtained in the Southwest CRD. The regression estimate fell 3.50 percent absolute below the USDA-based proportion estimate while the ppes estimate was found to be 6.09 percent low. These same departure percentages represent 10.94 and 19.04 percent of the USDA-based estimate, respectively. Resulting estimate standard errors were 1.67 times higher for regression and 1.53 times higher for ppes in the Central as opposed to the Southwest CRD.

The less satisfactory performance in the Central Crop Report District resulted from a poor correlation between phase 1 and phase 2 proportion estimates. This low correlation was in turn traced to the fact that a significant amount of wheat had been plowed-down in some sample segments on the original phase 1 base date transparency. A test was run to determine if an earlier base date would produce correlations obtained (.8) in the Southwest CRD. This test was successful and suggested that inventory performance levels comparable to those achieved in Southwest should have been obtainable in the Central CRD.

Use of correct base date transparencies for phase 1 wheat estimation resulted in phase 1 to phase 2 correlations of .82 and .79 for the Southwest and Central CRD's respectively. These correlations were achieved when strata were pooled. Within stratum correlations varied from .54 to .83. The generally lower stratum-specific correlations suggest that some strata should be grouped or phase 2 sample sizes increased somewhat so as to allow a more accurate representation of the stratum phase 1 to phase 2 relation.

Interestingly, phase 1 cultivated land proportion estimates gave a phase 1 to phase 2 (wheat) correlation of .89 in the Southwest CRD. The corresponding value for the Central District, however, dropped to .68. Dominance of the wheat crop in Southwest CRD may explain the former result, while the more complex multicrop patterns in the Central may be responsible for the latter result. In any event, the importance of inexpensive phase 1 cultivated land estimates, easily obtained in most agricultural situations, should not be overlooked as an inventory performance improvement option.

5.2 Cost-Effectiveness Comparison

The cost-effectiveness framework was used to compare the relative precision and cost performance of (1) the reference LACIE sampling system with stratification based on historical agricultural wheat area statistics, (2) the two phase sample procedure with machine-aided wheat classification at the second phase, and (3) the two phase sample procedure with multi-temporal manual processing at the second phase. Figure 2 illustrates the results of this analysis.

Cost ratio, correlation, and phase 2 variance data obtained for the Kansas Southwest CRD was used to construct the Figure. The LACIE reference system was defined to be a stratified random sample with phase 2 sample allocation to wheat density strata proportional to area. This reference system was defined to represent as closely as possible the LACIE second year procedure. Stratification on historical county wheat data was assumed to give a 4 to 5 times reduction in variance relative to unstratified random sampling. The total CRD survey budget determined earlier for the LACIE reference system was defined as the 100 percent inventory level.

Comparison of points P_0 and P_a in Figure 2 indicates that the two phase sample with computer processing at phase 2 should give greater than a two fold increase in precision relative to the reference LACIE system. Alternatively, the same LACIE reference system standard error at point P_0 should be obtainable with less than one half to one fifth the reference system cost by using the two phase sample approach. This cost relationship can be seen by projecting* the curve containing P_a to the level of P_0 .

Similar comparison of P_0 with P_b indicates a greater than 10 fold increase in precision relative to the LACIE reference system may be achievable with the two phase sample using manual wheat classification at phase 2.

Comparison of P_a and P_b shows a four fold increase in precision when two phase sampling with manual as opposed to machine-aided wheat classification is employed. A similar reduction in cost is indicated.

It should be emphasized that these results are limited to the Kansas data set examined and the particular sample design assumptions made. The authors submit that the important information here is not the exact cost or precision improvement values, but rather the relative performance relationship between the two phase and single phase (reference) sample system.

6. CONCLUSIONS

The sampling and measurement methods described in this study are of practical utility in many agriculture inventory situations. Optimum allocation of

*Using the shape relationship of the curve containing P_b . The shape relationships are approximately equivalent.

sample units to control precision of acreage estimation is a common sampling concern. The spatial information provided on the full-frame Landsat imagery can, as demonstrated in this study, be used to cost-effectively stratify a population of segments so as to minimize final estimate variance. For the Kansas test areas examined in this study, it appears that remote sensing-aided inventory systems can perform with high precision and accuracy at the Crop Reporting District level.

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TABLE 1: RESULTING TWO PHASE KANSAS SOUTHWEST CRD WHEAT PROPORTION ESTIMATES

(ACREAGE SOWN 1973 - 1974)

USDA-Based	Two Phase Regression			Two Phase ppes		
Estimate	Estimate	Std. Error	R.D. USDA vs. Two Phase	Estimate	Std. Error	R.E. USDA vs. Two Phase
27.63	28.31%	1.68%	2.42%	28.30%	0.40%	2.42%

$$R.D. = \frac{\text{SAMPLE ESTIMATE} - \text{USDA ESTIMATE}}{\text{USDA Estimate}} \times 100$$

TABLE 2. COUNTY TWO PHASE RESULTS FOR THE KANSAS SOUTHWEST CRD
(1973 - 1974)

COUNTY	WHEAT PROPORTION ESTIMATE DIFFERENCE (Two Phase - USDA Based)
Hamilton	-1.95%
Kearny	-5.95%
Finney	0.25%
Hodgeman	5.33%
Stanton	-6.66%
Grant	0.27%
Haskell	-0.91%
Gray	2.08%
Ford	9.54%
Morton	-0.74%
Stevens	-3.48%
Seward	-0.19%
Meade	1.74%
Clark	2.56%

Ave. Difference sign considered = 0.18%

Ave. Difference sign ignored = 2.93%

Figure 1: TWO PHASE SAMPLE FRAME FOR WHEAT ACREAGE ESTIMATION

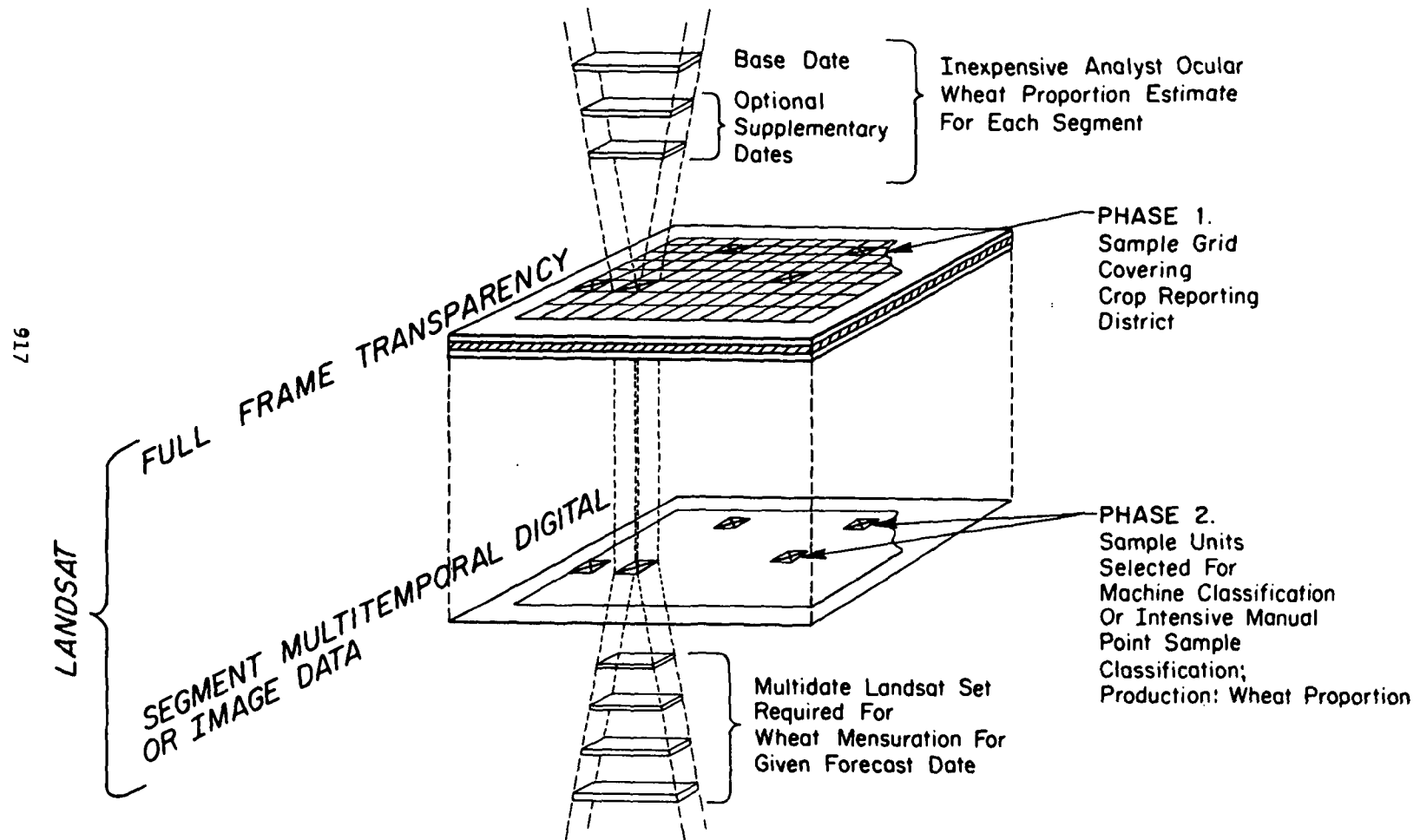
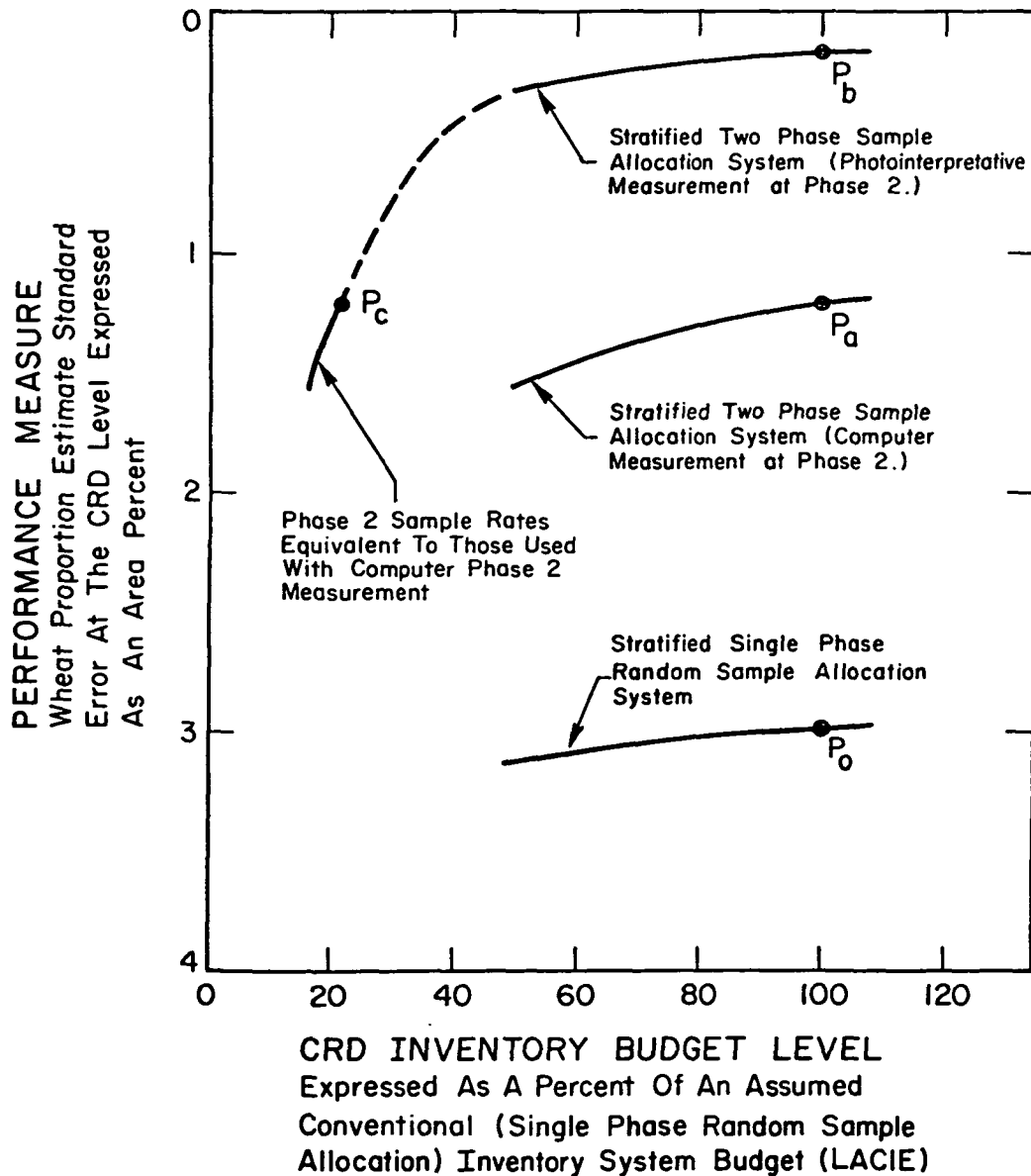


Figure 2: COST-CAPABILITY COMPARISON OF LANDSAT INVENTORY SYSTEMS USING TWO PHASE VERSUS SINGLE PHASE SAMPLE ALLOCATION STRATEGIES



CLASSIFICATION OF LANDSAT AGRICULTURAL DATA BASED UPON COLOR TRENDS

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SUMMARY

Historically, supervised classification procedures are usually "trained" by photo-interpreters who preprocess the data. This preprocessing consists of identifying and labeling training areas by analysing photo products produced from the digital Landsat data. An oversimplification of this procedure is that the photo-interpreters label a field according to whether or not its observed color (determined by the false color IR film product produced from a composition of landsat bands 4, 5, and 7) coincides with the expected color of known crops at acquisition time t . Since the success of most, if not all, supervised classification procedures is highly dependent upon the success of the photo-interpreters, multiple acquisitions obtained throughout the growing season are desired in order to insure sufficient confidence in the field labeling. In fact, very few errors are encountered if the photo-interpreter has imagery available at the various growth stages of the crops he is interested in identifying. Based upon this assumption, it seemed feasible to automate a part of the photo-interpreters logic process, that of labeling or classifying fields (hence pixels) according to their color trend. The purpose of this paper is to present such a classification procedure. The decision rules have been developed for classifying an unknown observation by matching its color trend with that of expected trends for known crops. The results of this procedure have been found to be encouraging when compared with the usual supervised classification procedures.

1. INTRODUCTION

Historically, the majority of crop inventoring of agricultural regions using Landsat multispectral scanner data have been performed using supervised classification procedures [MacDonald 1975]. This type of procedure usually consists of having trained photo-interpreters (PI) define and label homogenous areas found on a film product produced from the digital data. A principle product used in this identification is a false color IR produced from a composite of Landsat bands 4, 5, and 7. In defining and labeling these homogenous areas, the PI selects areas which are representative of the major crops to be classified in the test segment. Since the performance of the classifier is highly dependent upon its training inputs (hence the PI labeling), it is often desirable and necessary for the PI to analyze multiple acquisitions of the same test area throughout the growing season. An oversimplification of this procedure is that the PI labels a field, crop x , according to whether or not its color at acquisition time t coincides with the expected color for crop x at time t . By repeating this process for each acquisition, the PI obtains a degree of confidence in the labeling of the training inputs. In this paper, I have developed a simple procedure which attempts to automate this portion of the PI logic process, that of labeling fields or pixels according to their observed color trend. The results of this procedure are compared with a supervised classification procedure, both in terms of spacial properties (preservation of field structure) and as crop proportion estimates. Due to the nature of the available data, I have restricted my attention to the problem of separating wheat from all non-wheat by using Landsat imagery obtained from at least three distinct growth stages for wheat.

2. PROCEDURE

Engvall, Tubbs, and Holmes (1977) have shown that certain agricultural crops could be classified according to their temporal trend. In order to detect the temporal trends, it was necessary to transform the original four dimensional Landsat space S_L onto a two dimensional space S_D . Then an unknown observation is classified by matching its temporal trend with the temporal trend for known crops. In their paper, the transformation was based upon band differencing and ratioing, in order to take advantage of the spectral variability over varying ground targets. In this paper, I have developed a procedure which is also based upon classifying temporal trends, however I have projected the original Landsat space S_L onto a hopefully more familiar space, one that is equivalent to plotting points in the standard CIE Chromaticity diagram [3].

As mentioned in the introduction, the analysis of false color IR film product obtained periodically throughout the growing season is usually sufficient to insure that the PI correctly label the training inputs. This is particularly true if certain auxillary information (cropping practices, updated weather reports, etc.) is also available. The PI then labels a field A, crop x, if the observed color (red on film implies a green-like target, non-red implies a non-green like target) agrees with the expected color for crop x at acquisition time t. For example, if the PI suspects field A is winter wheat, then he expects to see a non-red (preemergence), red (emergence to heading), then non-red (harvest). There will be some variability in this general trend, however variance could be anticipated according to the auxillary information. Since the film product is produced directly from the digital data, it seems feasible that one could determine directly (without analyzing the film product) whether or not an observation is red or non-red. Then by repeating this procedure for each acquisition, one would be able to classify an unknown observation according to its agreement or disagreement with the expected trends for known crops.

Mathematically this is equivalent to defining a transformation from the spectral space S_L onto 0 to 1 (0 = non-red, 1 = red). Let $X_t = (x_{1t}, x_{2t}, x_{3t}, x_{4t})$ represent the four dimensional row vector corresponding to the multispectral scanner data ($X_t \in S_L$) acquired at time t. Due to the lack of variability in the scanner data and to the inconsistency in the dynamic range of the spectral bands, it is often necessary to enhance the data before processing the color product. One such approach is to define a linear map on X_t by

$$x_{jt}^* = s_j x_{jt} + b_j \quad \text{for } j = 1, 2, 3, 4. \quad (1)$$

where s_j, b_j are such that $\bar{x}_j - 3sd_j = 0$ and $\bar{x}_j + 3sd_j = 255$, when $\bar{x}_j, sd_j$ are the sample mean and standard deviation for band j and (0,255) represents the dynamic range of the photo processor. Now define the following transformation

$$Y_t = A X_t^* \quad (2)$$

where $X_t^* = (x_{1t}^*, x_{2t}^*, x_{3t}^*, x_{4t}^*)$, $br = x_{1t}^* + x_{2t}^* + x_{4t}^*$ and

$$A = \begin{bmatrix} 0 & 0 & 0 & 1/br \\ 0 & 1/br & 0 & 0 \\ 1/br & 0 & 0 & 0 \end{bmatrix}$$

Thus X_t^* is mapped onto $Y_t = (y_{1t}, y_{2t}, y_{3t})$ which is equivalent to $Y_t = (y_{1t}, y_{2t}, br)$ since $y_{1t} + y_{2t} + y_{3t} = 1$. Note that Y_t is the Trichromatic coefficient [3], and $y_{1t} y_{2t}$ are the chromaticity coordinates which can be plotted on the CIE diagram. These coordinates can be used to determine whether or not X_t is red or

non-red when projected onto the color plane S_C . Let R denote the red region of the color plane and NR the non-red region. If $(y_1, y_2) \in R$, then let $d_t = 1$, otherwise $d_t = 0$. By repeating this process for each acquisition t , $t=1,2,\dots,n$, we have reduced a $4 \times n$ dimensional row vector $X = (X_1, X_2, \dots, X_n)$ onto a n dimensional row vector $D = (d_1, d_2, \dots, d_n)$, where $d_j = 1$ if the j^{th} acquisition of the unknown observation X is red like on the film product.

3. CLASSIFICATION PROCEDURE.

Suppose that there are m different crops to be classified, denoted by $C_1, C_2, \dots, C_m$. Let $G_j =$ the set of D_i 's that are to be associated with crop j , $j=1,2,\dots,m$. Let $X = (X_1, X_2, \dots, X_n)^k$ be an arbitrary observation to be classified. Since there are 2^n possible outcomes and n is usually small ($n \leq 6$) the matching problem is fairly trivial. For example, assume that $n=4$, where the acquisitions are spaced according to the distinct growth stages for wheat. Let C_1 denote the class of pure wheat, C_2 denote the class of possible wheat, and C_3 denote the class of non-wheat, where $G_1 = \{D_1\}$, $G_2 = \{D_2, D_3, D_4\}$ and $G_3 =$ the remaining 12 outcomes and

$D_1 = (0,1,1,0)$	ideal wheat ($z=6$)
$D_2 = (0,1,0,0)$	possibly early maturing wheat ($z=2$)
$D_3 = (0,0,1,0)$	possibly late developing wheat ($z=4$)
$D_4 = (1,1,1,0)$	possibly very early developing wheat ($z=7$).

Class C_2 is defined to account for the variability of the wheat fields within a sample segment and the proportion of observations falling into this class could be weighted according to the nature of the auxiliary information. Since the D vector is made up of zeroes or ones, there is an easy procedure for matching unknown observations with the 2^n possible outcomes. Let $z = d_1 + 2d_2 + 4d_3 + 2^{n-1}d_n$.

Now the comparison of the color response for an unknown observation with that of known crop consists of comparing integers. That is, in our example if the z value for the unknown observation was a 6, then it was classified as pure wheat, if $z = 2,4,7$ then it was classified as possible wheat and would be weighted according to the available information, and if the z value was not 2,4,6,7 it was classified as non-wheat.

4. RESULTS

The proposed classifier (color) was applied to 19 different Landsat data sets collected during the 1974-1975 growing season throughout the major wheat producing regions of the United States. To aide in the evaluation of this procedure, the 19 data sets were classified using three different procedures. The first (MLE) is maximum likelihood classification using any or all of the available Landsat acquisitions. The results were deemed satisfactory by the PI using ad-hoc investigation. The second procedure (B104) is also based upon maximum likelihood classification where the data sets were classified using all available acquisitions (multitemporal classification). The third procedure is the non-supervised classification procedure (DELTA) as proposed by Engvall, et al. (1977). The results (wheat proportion estimates) have been summarized in Table 1. Table 2 lists correlations and linear regression coefficients.

Table 1: Wheat Proportion Estimates

Data Set	Procedures			
	COLOR	MLE	B104	DELTA
1	11.9	18.0	12.6	6.0
2	15.9	26.0	35.2	**
3	20.0	7.0	10.9	27.5
4	7.7	2.0	7.4	15.9
5	14.2	14.6	18.7	11.3
6	22.6	36.9	33.1	24.2
7	20.7	8.0	13.8	19.1
8	9.1	15.3	15.3	34.5
9	1.6	0	.2	7.0
10	32.1	21.3	23.2	29.7
11	15.1	12.7	2.4	8.7
12	18.9	.3	5.3	3.4
13	34.9	40.0	39.5	45.8
14	9.6	8.5	8.5	5.1
15	16.0	8.8	7.7	.5
16	9.4	13.7	13.7	1.5
17	23.1	46.7	12.3	54.6
18	3.4	20.0	19.3	7.4
19	26.6	18.0	15.2	7.0
$\bar{X}$	16.1	16.7	15.4	17.1
5D	9.0	13.0	10.7	15.7

** Dates were unsatisfactory

Table 2: Correlation and Regression Coefficients

Source	B_0	B_1	R^2	r
Color x MLE	8.14	.47	.46	.68
Color x B104	10.00	.35	.35	.64
Color x DELTA	7.69	.54	.41	.59

5. CONCLUSION

As mentioned in Engvall, et al (1977), the difficulty in evaluating or selecting "best" classification results in absence of ground truth information has been a real problem to remote sensing investigators. This is particularly true if one wishes to make decisions based solely upon fixed decision rules. Recently, there has been a trend toward developing simple (minimum setup and computer time) classification procedures to aid in this decision process. In this paper, I have introduced such a procedure. One of the main advantages of this procedure is that the transformation is similar to the one used in producing the color film product. This is particularly important when one considers the nature of this transformation. The transformation is many to one, which means that different points in the spectral space are mapped to the same

color. Mathematically this is equivalent to saying that the inverse transformation is not unique. This is evident when the PI defines two training areas as identical crops, only to find that the classifier finds that they are entirely different. This problem is particularly apparent in defining representative multitemporal training areas. For this reason I wanted to classify a sample segment using the same space in which the training areas were defined and labeled. It was my hope that the color process (hence the proposed classifier) could be used to separate major crop types (wheat from non-wheat), whereas it may not be able to distinguish different varieties of wheat.

The preliminary results of this investigation have been encouraging. There seems to be a very good agreement between the classification results and the PI labeled training areas. I stated in the introduction that I wanted to compare this procedure with some of the usual procedures using both spacial properties and proportion estimates. Due to lack of resources, I was not able to display any of the class maps generated using this procedure, however they were very satisfactory (comparison of computer printer plot with 5 x 6 color film product). The proportion estimates also seemed satisfactory, although one must always guess at what is a satisfactory answer.

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THE USE OF LANDSAT DIGITAL DATA TO DETECT AND MONITOR
VEGETATION WATER DEFICIENCIES

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ABSTRACT

In the Large Area Crop Inventory Experiment a technique was devised using a vector transformation of Landsat digital data to indicate when vegetation is undergoing moisture stress. A relation was established between the remote-sensing-based criterion (the Green Index Number) and a ground-based criterion (Crop Moisture Index).

1. INTRODUCTION

Meteorological indexes which provide methods of computing the extent and severity of general drought have been developed. The most common of these are the Palmer and Foley drought indexes [1]. The Palmer drought index is the more involved and the most satisfactory solution to the problem of combining precipitation and temperature data and producing a predictor variable [2]. During periods when a major drought is developing and spreading, it provides a means for routinely assessing the areal distribution of the various degrees of drought severity [3].

Palmer used a two-layer soil moisture model for estimating soil moisture deficiency on a month-by-month basis [4]. These monthly variations are adequate for the study of drought; however, they do not reveal the shorter periods of soil moisture fluctuations which are important during strategic phases of plant growth. The earlier drought study was modified by Palmer to calculate a weekly index of soil moisture related to crop water requirements [3]. This index uses the same two-layer models to compute a weekly hydrological balance. It is published in the United States as the Crop Moisture Index (CMI). Although the CMI provides an indication of current plant-water relationships, it requires climatological analysis of a long record in order to derive the constants which define the moisture characteristics of the climate in the area of interest. This paper describes a procedure using criteria based on remote sensing to detect and monitor crop moisture deficiencies without analyzing a long record of climatological data.

2. METHODS

The procedure described in this paper was devised in an attempt to quantify the subjective judgment of the analyst-interpreter in deciding that a region is or is not drought affected. The data used are Landsat multispectral scanner (MSS) values for Large Area Crop Inventory Experiment (LACIE [5]) sample segments throughout South Dakota, which were acquired during the 1975 and 1976 crop years (fig. 1),

*Under National Aeronautics and Space Administration (NASA)
Contract NAS 9-15200.

and the CMI values reported weekly during these crop years by the U.S. Department of Agriculture (USDA) for each crop reporting district (CRD). Using the ideas presented by Kauth and Thomas [6], we devised a summary number, the Green Index Number (GIN), which was computed for each acquisition of each segment. Each segment was classified twice as drought affected or normal - first using only the GIN (remote-sensing-based criterion) and second using only the CMI (ground-based criterion). The results of these two classifications then were compared (table 1), and a contingency table of the GIN and CMI classifications (table 2) was prepared.

The GIN is defined as follows: First, the data in the segment acquisition are summarized by clustering using the Iterative Self-Organizing Clustering System (ISOCLS) algorithm [7] as implemented on the Earth Resources Interactive Processing System (ERIPS [8]) on the special purpose processor. (This parallel processor clusters a segment in approximately 30 seconds.) The clustering procedure summarizes the segment in 20 or fewer cluster means in the four Landsat channels. The count of pixels belonging to each cluster is also calculated. Each mean vector x^i is then transformed by

$$y^i = Ax^i + b' \quad (1)$$

where

$$y^i = \begin{bmatrix} y_1^i \\ y_2^i \\ y_3^i \\ y_4^i \end{bmatrix} = \begin{matrix} \text{a vector representing the Landsat-1 version of the Kauth-Thomas trans-} \\ \text{formation of } x^i \text{ [6]; the subscript number indicates the Landsat channel,} \\ \text{and the superscript is the cluster number.} \end{matrix}$$

$$A = \begin{bmatrix} 0.4326 & 0.6325 & 0.5857 & 0.2641 \\ -.2897 & -.5620 & .5995 & .4907 \\ -.8242 & .5329 & -.0502 & .1850 \\ .2229 & .0125 & -.5431 & .8094 \end{bmatrix}$$

$$b' = (0.45, -1.50, 10.61, 2.22)$$

Each vector is inspected automatically, and any vector having values unreasonable for agricultural data is discarded using the following procedure.

A cluster y^i is accepted as good only if

$$\left. \begin{aligned} 30 &\leq y_1^i \leq 110 \\ -10 &\leq y_2^i \\ -10 &\leq y_3^i \\ -10 &\leq y_4^i \leq 10 \end{aligned} \right\} \quad (2)$$

The greenness level m of the soil line then is estimated by the minimum second channel value y_2^i for acceptable clusters. That is,

$$m = \text{MIN}_{i \text{ is good}} (y_2^i) \quad (3)$$

Then the green number g^i is computed for each cluster by

$$g^i = y_2^i - m \quad (4)$$

The value of g^1 should be a good measure of the green vegetation present on the picture elements (pixels) in cluster 1. Experience with spectral plots in the brightness-greenness plane and the corresponding imagery led to the following assumptions.

- $g^1 = 0$ indicates bare soil
- $g^1 = 5$ indicates a trace of vegetation
- $g^1 = 15$ indicates good cover of vegetation

Operating on these assumptions, we chose the level 15 and defined GIN to be the percentage of pixels in the entire image within clusters having green numbers greater than 15. This value was considered somewhat unstable for consecutive-day data where, for example, a cluster would slip from 15.1 one day to 14.9 the next day; therefore, cubic weighting was added to smooth this calculation in the following manner.

Let a cluster have green number g^1 and contain n pixels. Define the weighting factor w by

$$\left. \begin{aligned} w &= 0 & \text{if } g^1 < 11 \\ w &= 1 & \text{if } g^1 > 17 \\ \text{Otherwise,} \quad w &= \frac{1}{2} + \left[\frac{g^1 - 14}{4} \right] \left[1 - \frac{(g^1 - 14)^2}{27} \right] \end{aligned} \right\} \quad (5)$$

The cluster is counted as having $w \times n$ pixels with green numbers greater than 15. This curve makes a smooth transition from full counting to not counting as the green number decreases.

The GIN then is an estimate of the percentage of pixels in a Landsat scene having green numbers high enough (≥ 15) to indicate full cover of green vegetation. It is computed using only Landsat data. A sample spectral plot of green numbers versus brightness [6] is given in figure 2.

Having defined this segment summary number, the results had to be analyzed. For the test set used, it was impossible to make (1) year-to-year comparisons because of sparse Landsat acquisitions and important weather differences between 1975 and 1976, (2) area-to-area comparisons because of differing wheat proportions and haze effects, and (3) a direct comparison of GIN's and CMI's because the GIN contains crop stage effects not taken into account in calculating the CMI. This comparison also is confused by nonwheat crops with different crop calendars from those of wheat.

Therefore, the preferred technique for this analysis was a comparison of classifications. The plot of GIN versus time for a normal, predominantly wheat segment should follow a curve such as a in figure 3. If an observed point for a segment fell into the shaded region, the segment was classified as drought affected. The bounds for the shaded region were defined empirically as shown in figure 3, with t defined as the approximate spring emergence date in days. For different areas or years, the shaded area can be moved from side to side to match the greenup curve. The initial point in South Dakota was usually near day 110 ($t = 110$). This classification was compared to a classification based on the CMI for CRD's, wherein a CRD was classified as drought affected if the CMI fell below -0.5 for 2 consecutive weeks. Both classifications were restricted to similar time frames. Classification was performed only for data between April 1 and July 10.

3. DATA AND RESULTS

The data used in this study consisted of all LACIE segments in South Dakota which had at least 5 percent wheat as measured by the LACIE Classification and Mensuration Subsystem (CAMS [9]) in the 1976 growing season. This definition yields 17 segments with 34 possible classifications. Of the 34, 12 had either

insufficient data during the growing season or data were inaccessible for other reasons. The final data set contained 22 segment years¹ for 13 LACIE segments (fig. 1, table 1). The contingency table (table 2), which applies the two classification methods to the 22 good segment years, shows that the classifications based on the CMI and GIN are related. It was concluded that the GIN is detecting moisture through crop responses.

An inspection of the five disagreements on the classification results (table 1) disclosed that on two segments the GIN algorithm was confused by a lake. Three of the segments were on the edge of their CRD's, and the CMI classifications may not reflect the actual conditions in these segments. One segment was located on the eastern edge of the CRD where heavy rains occurred at the weather station located in the Black Hills in the western part of the CRD, causing a possible incorrect condition to be reflected by the CMI.

Examples of the segment classification procedure are shown in figures 4 and 5. The GIN indicates that 1975 was normal for the entire crop season for segment J (fig. 4). In 1976, the GIN indicated that by May 24 there was moisture stress in segment J. This indicates that the GIN detected vegetation moisture stress at the same time as the CMI. Segment L (fig. 5) experienced drought as indicated by both the GIN and the CMI during the 1975 crop year. In 1976, the GIN indicated moisture stress on May 26, which was confirmed by the CMI.

4. DISCUSSION

The results reported cover a first attempt at measuring drought conditions using Landsat data. Preliminary checks indicate that this procedure works in the U.S. Great Plains. More recently, we have developed a program using raw image data and avoiding the clustering procedure, enabling the generation of GIN's with any threshold. This new procedure will be utilized in continuing investigations.

5. CONCLUSIONS

A technique was developed using Landsat digital data from 9-by-11 kilometer sample segments, which indicates when agricultural vegetation is undergoing moisture stress. A relation between this technique, which utilizes remote sensing, and a ground-based criterion (the CMI) has been shown. Indications are that this procedure may be capable of detecting crop moisture deficiencies in areas of the world where ground information is not available or reliable.

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¹A segment year is defined as an observation of 1 segment for 1 year.

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TABLE 1. RESULTS OF GIN AND CMI CLASSIFICATIONS

D = Drought conditions W = Normal conditions - = No data				
Segment	1975		1976	
	GIN	CMI	GIN	CMI
A	W	W	-	D
B	-	W	W	D
C	W	W	D	D
D	W	W	D	D
E	W	W	D	D
F	W	W	W	D
G	W	W	W	D
H	W	W	D	W
I	W	W	-	W
J	W	W	D	D
K	W	W	D	D
L	D	D	D	D
M	-	D	W	D

TABLE 2. CONTINGENCY TABLE OF GIN AND CMI CLASSIFICATION METHODS

		CMI		
		Normal	Dry	
GIN	Normal	10	4	14
	Dry	1	7	8
		11	11	22

$\chi^2 = 7.07$ with 1 degree of freedom.

$\hat{p} = 0.0082$ = level of significance.

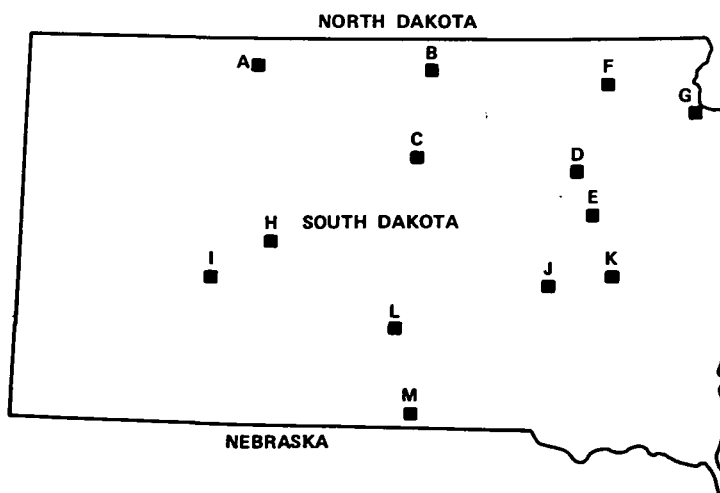


FIGURE 1. SEGMENT LOCATIONS. Map of South Dakota showing locations of LACIE 9-by-11 kilometer sample segments.

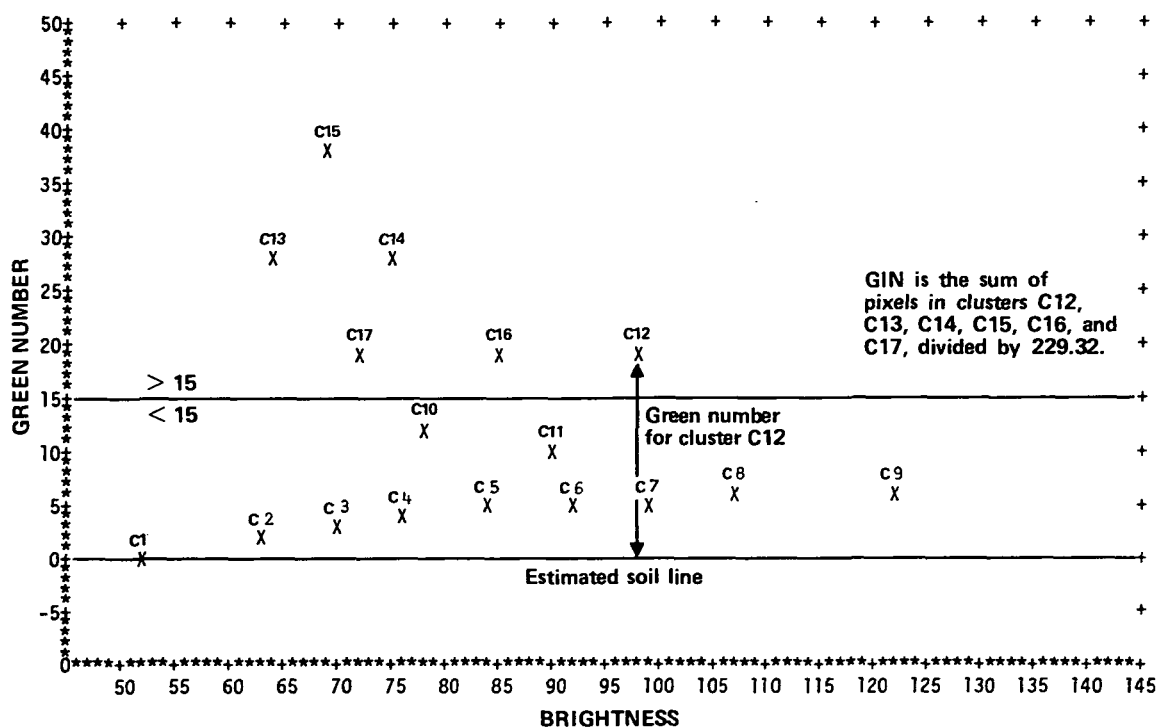


FIGURE 2. SPECTRAL PLOT. Sample spectral plot of cluster statistics.

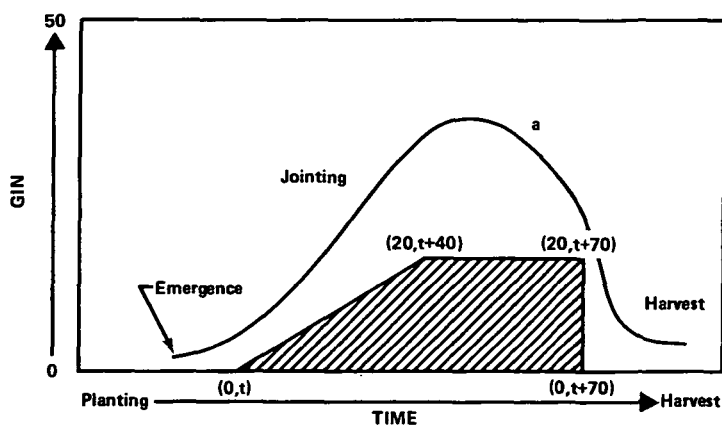


FIGURE 3. PLOT. GIN versus time for a normal, predominantly wheat segment.

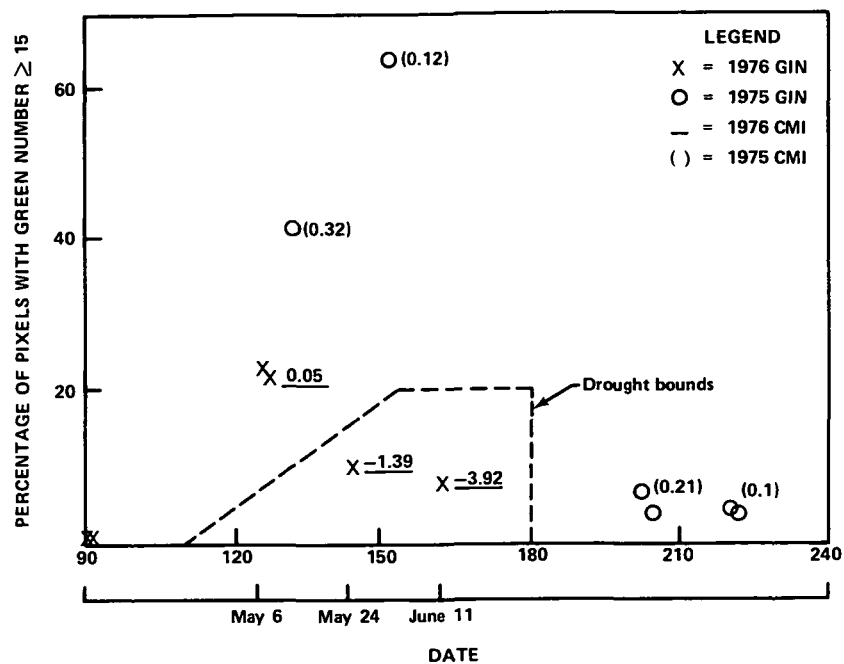


FIGURE 4. GRAPHIC PLOT. GIN versus time with CMI values for segment J.

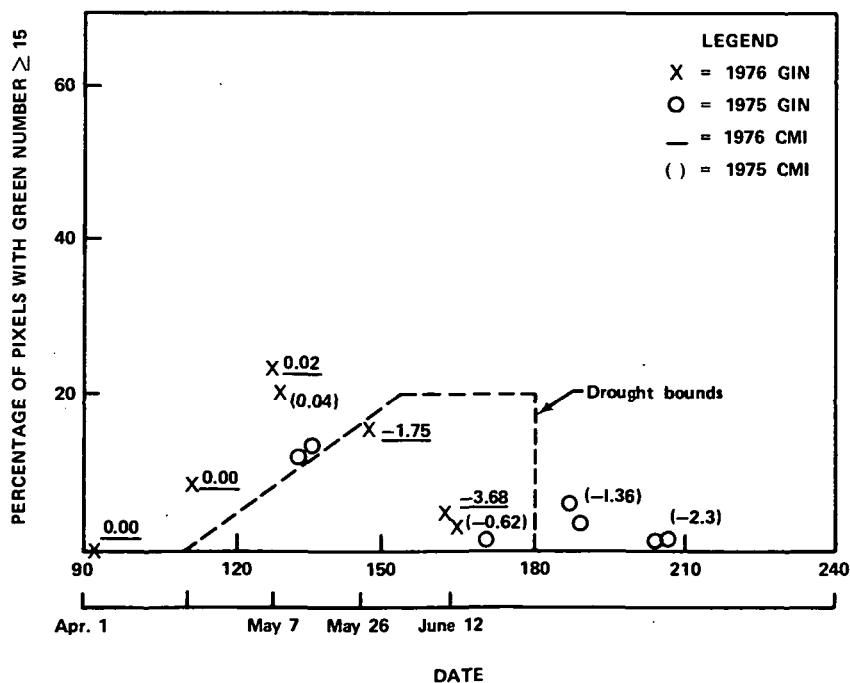


FIGURE 5. GRAPHIC PLOT. GIN versus time with CMI values for segment L.

PRE-VISUAL DETECTION OF STRESS
IN PINE FORESTS

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ABSTRACT

Remote detection of stress in forest trees prior to the appearance of visible symptoms has been a dream of foresters for several decades. Laboratory data indicate that pre-visual detection of some types of insect and disease attacks should be possible, either photographically or with multispectral scanners. All but two attempts to realize this potential under field conditions have produced negative results, and pre-visual detection has been largely discarded.

Extensive tree mortality due to recent attacks by the southern pine beetle (Dendroctonus frontalis Zimm.) has resulted in renewed interest in pre-visual detection of forest stress. Interest persists despite the lack of success at pre-visual, or early, detection of attacks by another bark beetle (Dendroctonus ponderosae Hopk.) realized by the U.S. Forest Service in the Black Hills during 1967-72. This report summarizes a review of available information relating to pre-visual, or early, detection of forest stress with particular reference to detection of attacks by pine bark beetles.

Available data indicate that early, or pre-visual detection is more likely with multispectral scanners (MSS) than with camera systems. Preliminary efforts to obtain early detection of attacks by pine bark beetles, using MSS data from the ERIM M-7 scanner, have not been sufficiently successful to demonstrate an operational capability, but indicate that joint processing of the 0.71 to 0.73, 2.00 to 2.60, and 9.3 to 11.7 μ m bands holds some promise. Ratio processing of transformed data from the 0.45 to 0.52, 1.55 to 2.60, and 4.5 to 5.5 or 9.3 to 11.7 μ m regions appears even more promising.

The view that prevention of beetle attack through better silvicultural treatment of pine stands will be more effective than control of the beetles is growing in popularity. When prevention through improved silvicultural treatment is economically feasible, early detection of beetle attack becomes an academic issue. However, early detection of moisture stress, an important predisposing invitation to beetle attack, may become more important as a guide to silvicultural treatment.

INTRODUCTION

Remote detection of stress in forest trees prior to the appearance of visible symptoms has been a dream of foresters for several decades. Laboratory data indicate that pre-visual, detection of tree stress due to drought and some types of insect and disease attacks should be possible, either photographically or with multi-spectral scanners. All but two attempts to realize this potential under field conditions in pine forests have produced negative results (Roller and Thompson, 1972; Fox, 1973). Due to the severity of current attacks by several forest pests, interest in pre-visual detection of forest stress remains high among foresters.

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Murtha (1972) has described four types of symptoms of stress, or damage, that can be detected from remote sensor imagery:

- Type I: Trees are completely, or almost completely, defoliated.
- Type II: Trees show some defoliation through the presence of bare branches, or malformation.
- Type III: Trees show abnormal foliage coloration.
- Type IV: Trees show no visible sign of damage but appear different from non-stressed trees in non-visible parts of the spectrum.

Truly pre-visual detection of forest stress requires detection of symptoms of Type IV. By definition, this requires the use of remote sensors operating at non-visible wavelengths. Although infrared sensitive films in camera systems, and the even larger and varied wavelength capabilities of optical-mechanical scanners, have received greatest attention, microwave sensors may also have possibilities.

This report grew out of an assessment of the opportunities for pre-visual detection of attacks by the southern pine beetle (*Dendroctonus frontalis* Zimm.) funded by the Texas Forest Service and the Department of Forest Science at Texas A&M University. The support of both organizations is gratefully acknowledged, but the views expressed are those of the author and do not necessarily represent the official opinions of either sponsor.

RATIONALE BEHIND THIS ASSESSMENT

Airborne remote sensing systems record, and thereby permit analysis of, spectral intensities of energy flux at the collecting aperture of the sensor. Only to the extent that this energy flux has been modified by an object can analysis of the remote sensor record provide information about that object. To detect the presence of tree stress, that stress must alter the energy flux from highly stressed trees, as compared to the flux from trees with lower levels of stress. Not only must the higher level of stress alter the energy flux, but that alteration must be large enough to exceed the detection threshold of the detection and analysis systems. Since beetles and most other causes of stress are too small to permit direct detection with airborne remote sensors, any assessment of changes in energy flux resulting from their presence must be based upon tree responses. A review of known effects of stress in pines is, therefore, an essential beginning of the present assessment.

REACTIONS OF PINE TREES TO STRESS

Many types of insect and disease attacks that do not result in visible symptoms, such as defoliation or chlorosis, disrupt the water metabolism of attacked trees and lead to water deficits and reduced growth. Low levels of atmospheric pollutants and low level nutrient imbalance may also result in growth loss of affected trees, but without disruption of water metabolism.

Effects of Water Deficits

All forest trees, even those growing in moist environments, have negative water potentials in their upper extremities most of the time. These negative hydrostatic pressures vary diurnally, and may reach -60 bars in conifers. Water stress is considered to be increasing when water potential decreases (becomes more negative). Under such conditions, both the upward flow of water to the crown and downward flow of water from crown to roots are reduced; foliar water content declines; stomates close; and rates of transpiration and photosynthesis are reduced (Crafts, 1968). Loblolly pines (*Pinus taeda* L.) subjected to drought or continuous flooding have been found to have higher levels of reducing sugars, nonreducing sugars, and carbohydrates in their inner bark than trees not so stressed (Barras and Hodges, 1969; Hodges and Lorio, 1969). Hodges and Lorio (1975) also reported that the resin of loblolly pines subjected to moisture stress had a lower proportion of resin acids relative to monoterpene hydrocarbons. A drop in oleoresin exudation pressure (OEP) is also found in pines with low water potential (Vite', 1961).

Stoszek (1973) reported that increasing stress in Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] is accompanied by the emission of a series of volatile/aromatic compounds with a specific order of appearance as stress increases. This sequence of release of volatile/aromatic compounds was shown to influence insect behavior and regulate the order in which specific insects began their attacks on stressed trees.

Changes in geometric arrangement of needles and branches have also been observed as a result of moisture stress. Working with watered and non-watered red pine (*P. resinosa* Aitk.) seedlings under greenhouse conditions, Fox (1976) found measurable differences in the angle that needle fascicles made with the branch, and McCarthy (1977) observed that needle fascicles were more open and the uppermost branches began to droop sooner on stressed than control trees.

Effects of Air Pollutants and Nutrient Imbalance

Tree species vary in their response to air pollutants and nutrient imbalance, and genetic differences within species have been reported (Berry, 1971 and 1973). The effects of ozone and sulfur dioxide on pine trees appear to be similar and independent of tree age (Berry, 1971; Miller, 1973). Ozone has been shown to reduce the rate of photosynthesis in ponderosa pine (*P. ponderosa* Laws.) and the reduction was greatest when ozone dosage was greatest (Miller, et al., 1969). High levels of soil nitrogen appear to increase, while high levels of soil phosphorus appear to reduce, the severity of damage by air pollutants (Cotrufo, 1974). Additional interactions between air pollutants and other damage agents are known and synergistic relationships between "smog" and pine beetles are known to hasten death of pines (Miller, 1973).

When pines react to air pollutants and nutrient imbalance, the commonest effects seem to be chlorosis; necrosis, in which needles die back from the tips; needle dwarfing, with production of shorter needles than normal; thinning of the tree crown; shoot elongation that is less than normal; or reduced growth. These symptoms are all visually detectable if the observer knows what to look for, but are difficult to detect in their early stages. Early detection, even if not truly pre-visual, would be of assistance to foresters, but is beyond the scope of this report.

Some possibly pre-visual effects have been described. Linzon (1967), and Miller and Evans (1974) identified changes in the mesophyll cells of pine needles caused by ozone, sulfur dioxide, and a variety of oxidants. Similar internal changes in broadleaved species have been identified as the basis for claimed pre-visual detection of disease in citrus trees (Colwell, 1960).

REMOTE SENSING IMPLICATIONS OF STRESS RESPONSES IN PINES

Several responses of pine trees to stress have implications favoring pre-visual detection of stress with remote sensors. These implications affect remote sensing opportunities in several parts of the electromagnetic spectrum.

Water Deficits and Reduced Transpiration

Water deficits and reduced transpiration occur together and imply lower foliar moisture content. In broadleaved species lower foliar moisture content is accompanied by an increase in foliar reflectance which is most pronounced and dependable at wavelengths longer than 1.0 micrometers (Figure 1), too long to be recorded photographically (Olson, 1967; Rohde and Olson, 1971). Similar results were obtained with red pine by Weber (1965), Rohde (1971) and Fox (1976), but all also reported detectable changes at visible wavelengths.

Since transpiration is a cooling process, reduced transpiration is usually accompanied by increased foliage temperatures. Heikkinen and Alger (1977) used an AGA Thermovision 680 system to determine apparent temperatures of tree crowns of severely stressed loblolly pines. Stressed trees were as much as 2°C. warmer than control trees even though the crowns of the stressed trees showed no visible symptoms of stress. Weber (1965) and Rohde (1971) determined foliage temperatures for red pine and found that stressed trees were as

much as 5.5°C warmer than control trees. In subsequent work under field conditions, it was found that ponderosa pines infested with western pine beetles (*Dendroctonus ponderosae* Hopk.) were warmer than non-infested trees under some conditions; but at the same, or lower, temperatures than non-infested trees under other conditions (Weber, 1969). Drying of the soil root horizon with a resulting increase in moisture stress of non-infested trees, and a midday transpirational lag that resulted in a thermal equilibration of infested and non-infested trees, were identified as factors contributing to these results. Tests with airborne thermal scanners showed that, although infested trees could be detected on the imagery, so many non-infested trees were classified as infested that the "false-alarm" rate was too high to justify operational use (Weber, 1976).

Chemical Changes

None of the known changes in tree chemistry appear directly detectable with presently available remote sensing systems. Changes in sugar and carbohydrate levels, resin acids, OEP, or release in volatile/aromatic compounds may prove important, however, once their effects on water metabolism or geometric arrangement of branches and foliage are known.

Geometric Changes in Foliage and Branches

When branch angle or foliage position changes, the projection of the tree canopy "seen" by a remote sensor changes. The relative proportions of the reflected or emitted signal coming from foliage, bark and ground background may vary widely and permit detection of tree stress. Such detection would not be truly pre-visual, but might make earlier detection of tree stress possible from an airborne vantage point. Active microwave sensors (radars) are particularly sensitive to changes in target geometry and their capabilities for detection of forest stress should be investigated.

Air Pollution Damage

Studies of smog-damaged ponderosa pine near Los Angeles, California, have shown that trees with thinning crowns, needle dwarfing, or chlorotic foliage can be detected in normal color photographs. Reflectance data from one study show a detectable increase between 0.52 and 0.68 μm , but negligible change in infrared reflectance out to 2.6 μm (Heller, 1969). No pre-visual detection was reported even though damage to mesophyll cells in needles should be most detectable in the 0.7 to 1.0 μm band, if present.

Exploitation with Remote Sensors

The only known case of supposedly pre-visual detection of stress in pines with camera systems is that reported by Fox (1973) for detection of *Fomes annosus* root rot in white pine (*P. strobus* L.). This result was achieved with color-infrared film exposed from an altitude of approximately 12,000 meters in mid-May of 1971, during the period of rapid shoot elongation. Visible symptoms of damage could not be detected from the ground sixteen months later. This study has not been duplicated and this evidence is, by itself, insufficient to justify operational use of photographic systems for pre-visual detection of stress in pine forests.

Single channel, optical-mechanical scanners have provided some cases where pre-visual detection of stress has been claimed, but not with sufficient accuracy to meet operational needs. Greater success has been realized with multi-spectral scanners (MSS) through ratio processing of signals in different spectral bands (Roller and Thompson, 1972). Extension of this work was planned as part of the U.S. Forest Service effort to obtain pre-visual detection of attack by the western pine beetle at the Black Hills Test Site in South Dakota in 1972-73. MSS data were collected with the Environmental Research Institute of Michigan's M-7 scanner in June 1972. Unfortunately, funds for processing these data were diverted to support LANDSAT investigations, and the data have not yet been thoroughly analyzed. A preliminary analysis of these data was made in March 1977, based on digitized data for twelve spectral bands

supplied by F. P. Weber, former study leader on the U.S. Forest Service Black Hills Study Team. Since a primary effect of pine beetle attack is a disruption of the water metabolism of the attacked trees, information on pine response to moisture stress was reviewed and the probable signal response in each spectral band determined. Probable signal response of several possible ratios of different spectral bands was also determined. Results of this analysis are summarized in Table I.

Based on these estimates of probable signal responses, it is apparent that normal color film should show stressed trees as a somewhat lighter green, with no real change in the blue or red spectral bands. Unfortunately, the small increase in green reflectance is no larger than the variation in reflectance normally encountered between individuals of one species. It is also apparent that color-infrared film will add little discriminating capability to that of normal color films. Thus, it is most unlikely that any photographic system, or any system utilizing only the photographic spectrum, will achieve dependable, pre-visual detection of moisture stress. This analysis agrees with the field results of the U.S. Forest Service (Weber, 1976).

Analysis of the non-photographic spectral bands (MSS Channels 9, 10, 11, and 12) indicated that a combination of these bands would offer greater probability of pre-visual detection. With the generous assistance of F. P. Weber and R. D. Dillman, several combinations of these spectral bands were examined on the digital image analysis equipment available at NASA's Johnson Spaceflight Center, Houston, Texas. Results with Channels 8, 11, and 12 suggest that the inability to obtain dependable pre-visual detection of attack by the western pine beetle may have been due to inability to separate stressed and infested from stressed but non-infested trees. Time and funding limitations have prevented implementation of the suggested ratio processing, as of this writing. Ratio processing is expected to provide better discrimination of moisture stress, however, and work is continuing. If subsequent work confirms the apparent result of this preliminary analysis, it may be possible to use MSS systems to detect moisture stress in pine stands early enough to permit corrective action to be taken before beetle attacks or growth losses reach epidemic proportions.

THE SOUTHERN PINE BEETLE: A CASE ANALYSIS

Continuing outbreaks of the southern pine beetle (SPB) have reached epidemic proportions in the southeastern United States. Loblolly pine (Pinus taeda L.) and shortleaf pine (P. echinata Mill.) are the most commonly attacked species, but successful attacks on several other southern conifers have been reported. Excellent summaries of our knowledge of the SPB appeared in the comprehensive reviews of Thatcher (1960), Dixon and Osgood (1961), and Coulson, et al. (1972). This brief review was drawn primarily from these sources and is focused on those aspects of the beetle's life history that seem to relate most directly to possible pre-visual detection of SPB attack through airborne remote sensing techniques.

Adult beetles initiate an attack by boring through the bark and constructing a winding gallery in the phloem, cutting the cambium. This gallery has a distinct component that is more or less horizontal and perpendicular to the vertical flow of sap through the phloem (R. F. Billings, personal communication, 1977). Eggs laid along the sides of the gallery hatch in three to nine days under optimum conditions, and emerging larvae construct lateral galleries in the phloem that widen abruptly after the first molt. Four instars are normal with the last three tunneling into the outer bark where pupation occurs before the new adult beetles bore to the surface and emerge (Fronk, 1947). One complete generation can occur in as few as twenty-six days in the summer but may take more than three months in winter (Thatcher and Pickard, 1967).

Concurrent invasion of the blue-stain fungus *Ceratocystis minor* (Hedgc. and Hunt) usually accompanies attack by the SPB and the fungus may penetrate and block the first one or two xylem rings within four days (Caird, 1935). The decrease in phloem moisture content at the point of attack, noted by many investigators and considered essential to brood survival by Gaumer and Gara (1967), may be enhanced by the localized phloem block created by the adult gallery and intensified by *C. minor*. The presence of *C. minor* appears to be non-essential, however, for many trees killed during the 1946-48 outbreak of SPB in Florida showed no evidence of blue-staining (Hetrick, 1949).

Biochemical analyses of loblolly pines have revealed many changes in the chemical composition of the sap, resin, and inner bark following inoculation with SPB and associated fungi, with the greatest changes occurring in trees which had lost much of their root systems to rootlet pathogens (Hodges and Lorio, 1975).

Resin flow into wounds caused by SPB reduces the rate of gallery construction by beetles that are not "pitched out". As resin flow moderates gallery construction increases and most galleries are entirely resin free (McAndrews, 1926). The drop in OEP associated with successful attack by the SPB may result from two different causes: (1) decreasing water potential caused by the disruption of the tree's water metabolism by attacking beetles and associated fungi; and (2) decreasing water potential resulting from physiologic drought that could result from excessive competition for available soil moisture (St. George, 1930; Mason, 1971), excessive soil moisture and resultant poor root development and poor aeration (Hetrick, 1949; Lorio and Hodges, 1968a, 1968b), attack by root-rotting fungi such as *Armillaria mellea* (Vah.) (Hetrick, 1949) or *Fomes annosus* (Fr.) Karst (Skelly, 1975), or a combination of these factors. Thus, decreasing OEP and water potential may be both a symptom of attack by the SPB and a preliminary condition inviting such attack.

Death of the host tree follows mass attack by large numbers of beetles that concentrate in an imperfectly understood response to pheromone exudation by attacking beetles (Vite', et al., 1964; Vite', 1974; Silverstein, 1974). This mass attack massively disrupts the water metabolism of the host tree. Visible fading and then browning of the foliage occur (Doggett, 1971; Heikkinen and Alger, 1977) in a pattern similar to the changes reported in red pine seedlings under severe moisture stress (Weber and Olson, 1967). Fading and browning of the foliage may not occur until several weeks after the bark has fallen from large sections of the mid-bole, indicating that the tree is functionally dead. Many of the adult beetles have emerged and moved on before this bark-fall occurs.

Factors Affecting Susceptibility of Attack

There seems little doubt that a high level of moisture stress increases susceptibility of a tree to attack by SPB. Moisture stress may result from low rainfall (Craighead, 1925; St. George, 1930; Hetrick, 1949; Kalkstein, 1974, 1976), poor root development on wet sites (Lorio and Hodges, 1971; Lorio, et al., 1972; Hodges and Lorio, 1975), attack by root rotting fungi (Hetrick, 1949; Skelly, 1975), or competition between trees (Coulson, et al., 1974; Leuschner, et al., 1976; Billings and Pase, 1977). Competition appears to be of particular importance in pure stands of high basal area and larger than average tree size. In large areas of east Texas, dense stands of small saw-timber with basal areas approaching 120 square feet per acre are common and seemingly present optimum conditions for epidemic development of SPB (Coulson, et al., 1974). Past timber stand improvement projects that removed hardwoods and promoted higher density (closer spacing) of pines appear to have increased the risk of epidemic attack by the SPB, for between tree spacings larger than 20 or 25 feet have been found to curtail expansion of individual infestations (Gara and Coster, 1968).

Seasonal differences in the behavior of the SPB also influence the probability that a given tree will be attacked. During summer, most new attacks are associated with active infestations and result in the enlargement of these infestations (Thatcher and Pickard, 1964; Coster, 1967). During winter and

early spring, enlargement of active infestations is slow or non-existent but many new infestations occur through population dispersal (Gara, 1967; Coulson, et al., 1972). These two patterns of spread, often referred to as "spot growth" and "spot dispersal", have distinct remote sensing management implications.

Remote Sensing Management Considerations

Whenever most beetle activity is of the spot growth pattern, and particularly in summer when a complete generation of the SPB may require only 26 days, the likelihood of obtaining meaningful early detection of attacked trees with an airborne remote sensor is low. Time required to record, process, interpret and supply actionable information to control crews virtually precludes effective control action before adult beetles emerge and move to new trees. Even if information could be supplied to ground crews in time to permit effective control action, weather conditions during the spring-summer period are such that airborne remote sensors cannot be depended upon to obtain the needed coverage at the appropriate time(s).

Early detection during late fall or early winter could, however, provide for more effective implementation of control measures. Spot growth has slowed and beetle generations are longer than in summer. The relatively low mobility of the over-wintering population lengthens the effective response time for control actions. In addition, flying weather during this season is usually good enough to permit development of an acceptably dependable, operational detection system if detectable early symptoms of attack can be identified. It appears, therefore, that primary attention should be devoted to early-indicators of attack that will permit detection during the late-fall and winter period. This agrees with the findings of the U.S. Forest Service researchers studying early detection of the western pine beetle, for they reported that detection probability is highest in the fall (Weber, 1976).

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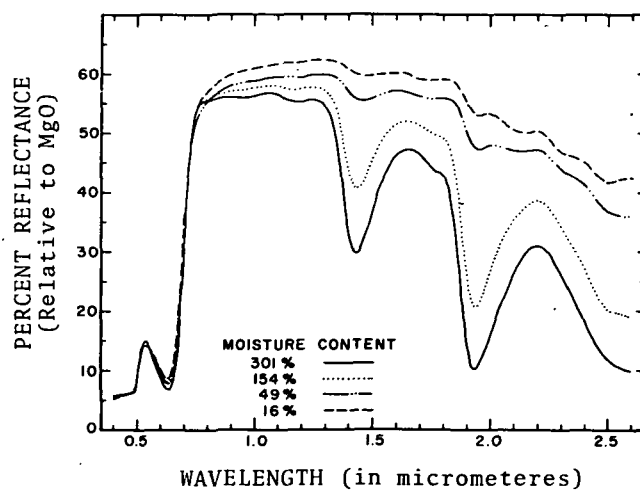


FIGURE 1. CHANGES IN REFLECTANCE OF A SYCAMORE LEAF AT DIFFERENT OVEN-DRY-WEIGHT MOISTURE CONTENTS AS IT DRIED IN AIR.

TABLE I. PROBABLE SIGNAL RESPONSE IN DIFFERENT SPECTRAL BANDS
AS A RESULT OF MOISTURE STRESS IN PINES.

<u>Data Channel</u>	<u>Spectral Band (in μm)</u>	<u>Probable Signal Response of Pine Trees Under Moisture Stress</u>
1	0.41 - 0.48	Reflectance should remain unchanged or increase slightly (Olson, et al., 1964; Fox, 1976).
2	0.50 - 0.54	Reflectance should remain unchanged or increase slightly (Olson, et al., 1964; Fox, 1976).
3	0.52 - 0.57	Reflectance should increase (Olson, et al., 1964; Fox, 1976).
4	0.55 - 0.60	Reflectance should increase (Olson, et al., 1964; Rohde, 1971; Fox, 1976).
5	0.58 - 0.64	Reflectance should increase slightly (Olson, et al., 1964; Rohde, 1971; Fox, 1976).
6	0.62 - 0.74	Reflectance should remain unchanged or increase slightly (Olson, 1969; Rohde, 1971; Fox, 1976).
7	0.67 - 0.94	Reflectance should remain unchanged or increase slightly (Olson, 1969; Rohde, 1971; Fox, 1976).
8	0.71 - 0.73	Reflectance should increase slightly (Olson, 1969).
9	1.00 - 1.40	Reflectance should increase slightly (Olson, 1969; Rohde, 1971).
10	1.50 - 1.80	Reflectance should increase (Olson, 1967; Rohde, 1971).
11	2.00 - 2.60	Reflectance should increase faster than at 1.50 - 1.80 μm (Olson, 1967; Rohde, 1971).
12	9.30 - 11.70	Emittance should increase (Weber, 1965; Rohde, 1971).
Ratio	$\frac{\text{Channel 3}}{\text{Channel 1}}$	Signal strength should increase slightly as stress increases.
Ratio	$\frac{\text{Channel 9}}{\text{Channel 5}}$	Signal strength should decrease as stress increases.
Ratio	$\frac{\text{Channel 10}}{\text{Channel 11}}$	Signal strength should decrease as stress increases.
Ratio	$\frac{\text{Channel 9}}{\text{Channel 11}}$	Signal strength should decrease as stress increases.
Ratio	$\frac{\text{Ch.10} + \text{Ch.11}}{\text{Ch.10} - \text{Ch.11}}$	Signal strength should increase rapidly as stress increases.

VIEW ANGLE EFFECT IN LANDSAT IMAGERY*

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ABSTRACT

The objective of this paper is to investigate the view angle effect in LANDSAT II imagery. The LANDSAT multi-spectral scanner scans over a range of view angles of -5.78 to 5.78 degrees. The view angle effect, which is caused by differing view angles, could be studied by comparing data collected at different view angles over a fixed location at a fixed time. Since such LANDSAT data is not available, consecutive day acquisition data were used as a substitute: they were collected over the same geographical location, acquired 24 hours apart, with a view angle change of 7 to 8 degrees at a latitude of 35 to 45 degrees. The study will show that there is approximately a 5% reduction in the average sensor response on the second-day acquisitions as compared with the first-day acquisitions, and that the view angle effect differs field to field and crop to crop. On false infrared color pictures the view angle effect causes changes primarily in brightness and to a lesser degree in color (hue and saturation). An implication of this study is that caution must be taken when images with different view angles are combined for classification and a signature extension technique needs to take the view angle effect into account.

I. INTRODUCTION

A multi-spectral scanner (MSS) measures the ground radiance by varying its view angle across the flight path of its carrier. Sensor outputs are dependent upon, among other things, the instantaneous view angle corresponding to each output. The effect caused by differing view angles is called the view angle effect or the scan angle effect. The objective of this paper is to investigate the view angle effect in the LANDSAT II MSS**. The LANDSAT MSS scans a swath of 185km width on the ground from a height of 920km, so the view angle varies between -5.78 and 5.78 degrees.

Some of the previous work on view angle effect are reported in the following. Reflection properties of natural objects such as clay, sand, soil, and grass turf at varying view angles and zenith angles were studied by Coulson et al. [1,2] in the laboratory environment. Smedes et al.[3] investigated the view angle effect in the imagery acquired over the Yellowstone National Park area by an airborne 12-channel scanner whose view angle varies from approximately minus 40 degrees to plus 40 degrees. They introduced a normalized scan-angle function in order to reduce the view angle effect. Their results indicate that the view angle effect is larger near the nadir (zero degrees) than at the larger view angles.

This paper documents an investigation of the view angle effect in the LANDSAT MSS based on analysis of its imagery. This task could be performed by comparing data collected at different view angles over a fixed location at a fixed

* This work was done under NASA contract NAS9-14350.

** Note that the results of this investigation are applicable to the LANDSAT I data because the two MSS's are identically designed.

time. However, such LANDSAT data is not available. Consecutive-day acquisition data were used as substitutes. Due to the LANDSAT orbit a certain portion of a LANDSAT full frame (185km by 185km on the ground) is also seen in a frame acquired on the next day [4,5]. Total view angle changes between consecutive-day acquisitions, which depend upon the latitudes of the ground area, are in the range of seven to eight degrees at latitudes of 35 to 45 degrees. Little attention to the view angle effect in the LANDSAT MSS has been paid in the past, possibly due to a common belief that such a small view angle variation would not affect the imagery. In this paper it will be shown that the effect is larger than expected. Moreover an attempt will be made to assess its rough order of magnitude.

II. MEASUREMENTS

One hundred and one consecutive-day acquisition pairs of LANDSAT subframes were used in this study. Each subframe consists of 117 scan lines by 196 pixels, covering an area of 9.0km by 10.8km on the ground. Among these frames there are 35 pairs of consecutive-day acquisition pairs which are 18 days (or one LANDSAT cyclic period with respect to the ground) apart (e.g. acquisitions on May 2, 3, 20, and 21). All the images are agricultural scenes from the United States and were acquired between April and August. The sun angles corresponding to the data are between 35 and 60 degrees. All images were screened visually and contain neither clouds nor visible haze.

The geometric registration of the imagery was assessed using a specially developed IMAGE REGISTRATION PROGRAM [6] for all acquisitions of the same location. The computed misregistration measurements ($\Delta x, \Delta y$) were rounded to the nearest integers and a simple shifting correction for misregistration was applied by these integer values along the scan line (Y direction) and/or the pixel direction (X direction). To further reduce the effect of misregistration, each frame (117 by 196) was smoothed by averaging and rounding the values in five scan line by five pixel areas, resulting in a 23 by 39 matrix.

Then scatter plots were made in the following manner. After the smoothing and rounding mentioned above are performed, two 23 by 39 integer matrices for the first-day and second-day acquisitions are obtained. A counter array, dimensioned 90 by 90 is defined and initialized to zero. The counters in the array are then incremented based on the values of geographically corresponding entries in the two matrices. If an entry pair for the first-day and the second-day acquisitions are 50 and 45, for instance, then the content of the counter at (50, 45) is incremented by one. This procedure is carried out for all 897 entry pairs from the two matrices. The final content of the counter array constitutes a scatter plot of the data. Resulting scatter plots are displayed as follows: the maximum counter value is found and the range from 0 to the maximum is divided into 10 equal ranges, which are denoted by ., 1, 2, ..., 9 in ascending order and are used in representing the scatter plot on a line printer. Blanks are used to represent null contents.

Since the LANDSAT MSS has four channels, four scatter plots were made for each consecutive-day acquisition pair. However, only the results for channel 3 will be shown because (1) all the four plots are fairly similar, (2) the effect of atmospheric conditions such as haze in channel 3 imagery is less than in channels 1 or 2, and (3) the effect of soil moisture in channel 3 imagery is less than in channel 4 imagery.

Figures 1(a), (b), and (c) show scatter plots made from three pairs of consecutive-day imagery on June 20 and 21, July 8 and 9, and July 26 and 27, respectively, from an area of 9.0km by 10.8km in Idaho. (It is extremely rare to have six straight acquisitions without clouds.) The diagonal line indicated by a series of '+' represents the $y=x$ line. A scatter plot should be interpreted as follows: Consider $x=50$, for instance, in Figure 1(a). The range in y is from 44 to 49. So areas with count 50 in the first-day acquisition imagery had changed to counts of from 44 to 49 on the next day. It is reasoned that this scattering is primarily due to the view angle effect.

From these scatter plots it is observed that the majority of points are below the $y=x$ line. That is, sensor outputs are generally smaller on the second day. This observation was confirmed by examining the 101 consecutive-day acquisitions mentioned earlier. Figure 2 shows a scatter plot where the x and y axes represent the entire subframe means on the first day and the second day, respectively. The least square solution $y=.95x$ was obtained. In other words there is a reduction of 5% in average sensor outputs from the first day to the second day acquisition. The following is a possible explanation of this phenomenon.

On the first of the two days the sensor and the sun are both on the same side of the area that is common in consecutive-day imagery (see Figure 3(a)) so that the sunny side of standing objects is seen from the MSS. On the otherhand, on the second of the two days the sensor and the sun are on opposite sides of the common area (see Figure 3(b)) so that more of the shady side of standing objects is seen. If this explanation is correct, the view angle effect will be dependent upon such factors as shapes of objects, leaf orientation, spaces and materials between objects as well as sun angles.

Therefore the view angle effect for spaced standing objects such as trees and corn plants is reasoned to be different than that for objects with smooth surfaces such as lakes and soil. This is illustrated in an example shown in Figure 4.

The scatter plot is made from acquisitions on August 6 and 7 from an area in the state of North Dakota. There are 6 large lakes, which cover approximately 5% of the entire area. Generally, counts below 25 are from these lakes. It is seen that counts from the lakes increased on the second day while those from other objects decreased slightly. It is generally observed that counts from lakes tend to increase on the second day which is consistent with expectations because of mirror image reflectance of the sun off the water.

To study the behavior of each field, 20 fields were defined on the acquisitions used in Figures 1(a), (b), and (c) (see Figure 5). Temporal trajectories of ten fields are shown in Figures 6(a), (b), where x and y axes represent the field means of channels 2 and 3, respectively. (The trajectories for the remaining 10 fields were not plotted because they overlap with the above.) It is seen that temporal trajectories make zigzag motions when acquisitions with different view angles are mixed. This means that signatures are dependent upon view angles. Therefore caution is recommended when acquisitions with different view angles are mixed for any signature extension schemes.

On Figures 6(a) and 6(b) it is also observed that the trajectory on the second day moves toward the origin as expected due to lower values in both channels. This trend was also observed in channels 1 and 4 imagery. In other words, the change between consecutive day acquisitions is roughly proportioned in all channels. If false color infrared films are made for consecutive day acquisition pairs, they will look similar in color (hue and saturation) but differ slightly in brightness. After channel-to-channel ratio processing discussed by Smedes *et al.*[3] images would be generally free from the view angle effect.

III. DISCUSSIONS

There are other possible causes to explain differences observed between consecutive day acquisitions. They include:

- (1) Effect due to precipitation - rain (possibly shower) may fall during a period of 24 hours.
- (2) Effect due to moisture change - sunshine and wind may dehydrate soil and vegetation, altering reflectance.
- (3) Effect of leaf orientation change due to wind.
- (4) Effect due to scene change by irrigation, plowing and harvesting.
- (5) Sensor noise and misregistration.

The degree of effects brought by these causes, except 5, differs from plant to plant or field to field. When a large number of cases are considered, all the above causes seem to act in a random fashion with zero bias. It seems to be a fair conclusion to say that the average of 5% reduction observed from the

first-day to the second-day acquisition can be attributed solely to the view angle effect. For a particular consecutive acquisition pair we are unable to assess the relative magnitude of the view angle effect to the above effects although we believe the view angle effect is dominant.

However the above does not imply the existence of uniformly applicable view angle correction functions. As was seen in Figures 1(a), (b), and (c), the magnitude of the random unpredictable variability is generally larger than that of the predictable variability (i.e. 5% reduction). Also as are seen in Figures 4, 5(a), and 5(b), the differences between consecutive day acquisition pairs are dependent upon types of fields and vegetation. Therefore it can be said that there are no uniformly applicable view angle correction functions for the view angle range of plus 3 to 4 degrees to minus 3 to 4 degrees. This is not contradictory to the result of Smedes et al.[3], because the view angles of their MSS changed plus 40 degree to minus 40 degree. A view angle correction function can be used to grossly normalize imagery data for such a large view angle change.

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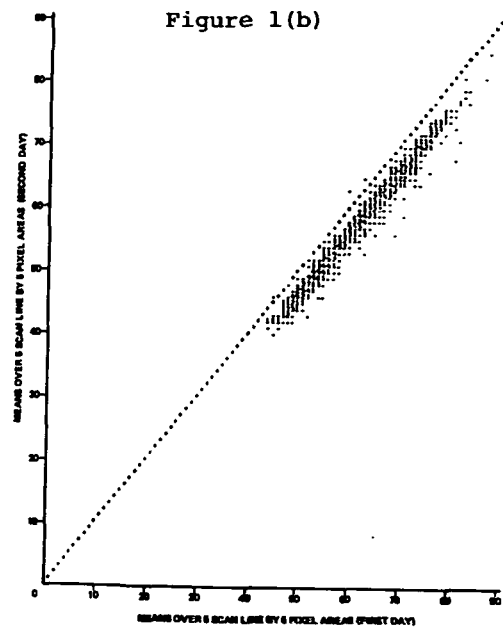
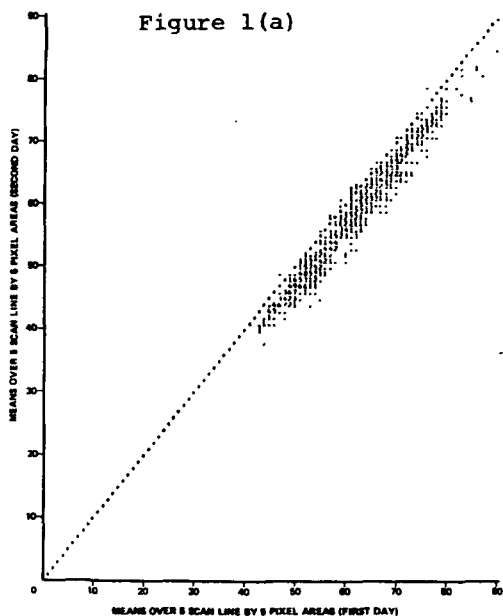


Figure 1(a) Scatter plot where x and y represent means over 5 scan line and 5 pixel areas on the channel 3 imagery acquired on June 20, and June 21, respectively.

Figure 1(b) Scatter plot where x and y represent means over 5 scan line and 5 pixel areas on the channel 3 imagery acquired on July 8 and July 9, respectively.

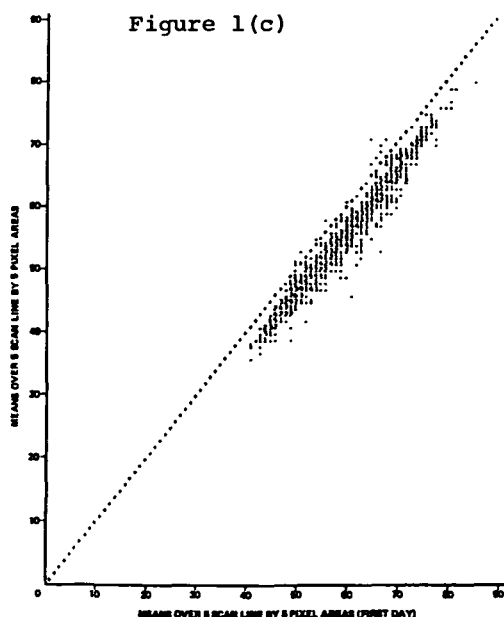


Figure 1(c) Scatter plot where x and y represent means over 5 scan line and 5 pixel areas on the channel 3 imagery acquired on July 26, and July 27, respectively.

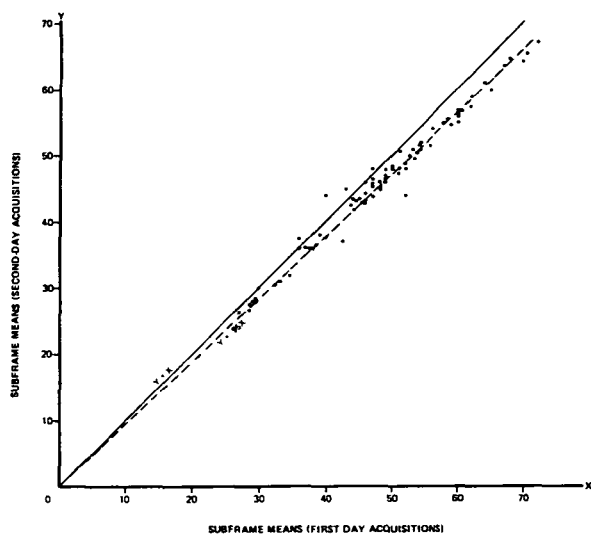


Figure 2 Scatter plot showing a 5% reduction in average sensor response on the second-day acquisitions as compared with the first day acquisitions.

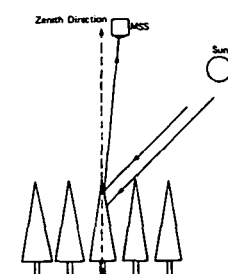


Figure 3(a)

Figure 3(a) Geometry of the sun, ground objects (trees), and the MSS for first-day acquisitions.

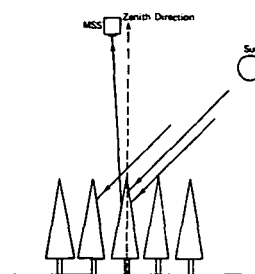


Figure 3(b)

Figure 3(b) Geometry of the sun, ground objects (trees), and the MSS for second-day acquisitions.

Figure 4 Scatter plot made from a consecutive-day acquisition pair where 6 lakes constitute approximately 5% of the total subframe area. Note that counts below 25 are from these lakes.

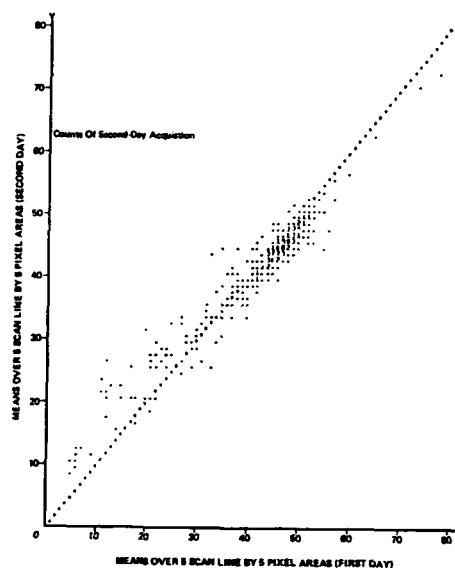




Figure 5 Channel 2 imagery of the subframe area used for Figures 1(a), (b), and (c) with 20 fields overlaid.

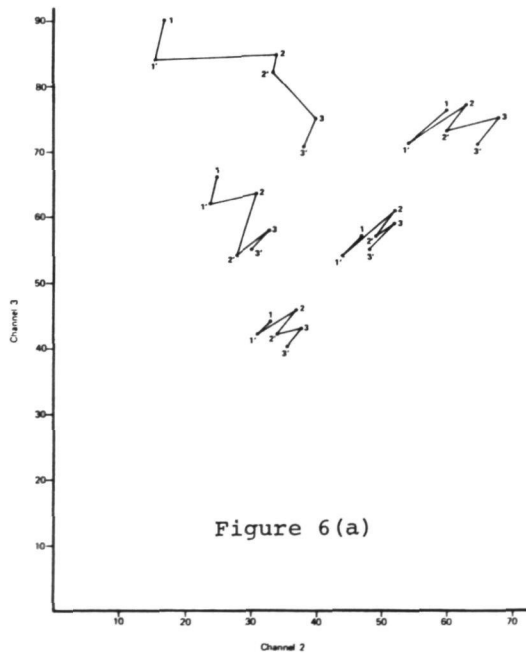


Figure 6(a)

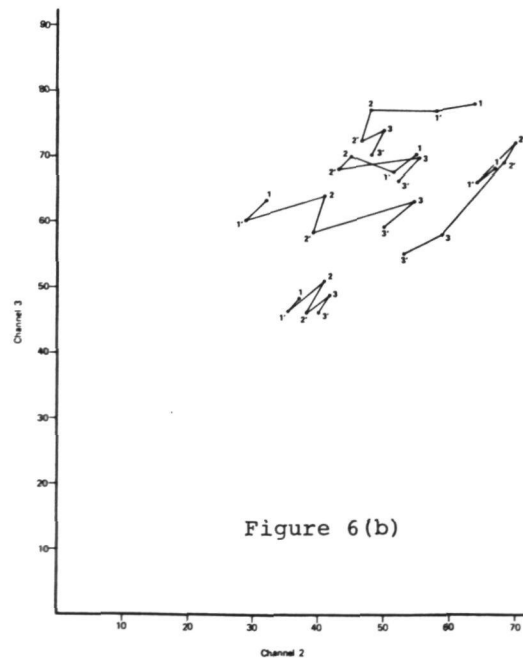


Figure 6(b)

Figures 6(a) and (b) Temporal trajectories of ten fields (1 = June 20, 1' = June 21, 2 = July 8, 2' = July 9, 3 = July 26, and 3' = July 27).

INTERACTIVE IMAGE PROCESSING TECHNIQUES USING THE PLESSEY IDP 3000

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SUMMARY

The authors are part of a team associated with the development of their Company's advanced Image Processor - the IDP 3000. The development activity is funded jointly by the Company and the U.K. Department of Industry, and as such represents an important contribution to the analysis systems for the user community. The Image Processor is typical of those used at university, state and national level and is entering into a market currently dominated by U.S. manufacturers.

The paper will present the image processing techniques through their application to user investigations. By this means it is hoped that the philosophy of interaction on which the development has been based, will be more readily comprehended. Particular emphasis will be placed on the three distinct modes of operation which distinguish this system from others.

The three modes of interactive operation, termed Alpha, Beta and Gamma Processing, reflect the need for a range of interactive processing techniques and will be presented in the session. Alpha processing is characterised by the instantaneous processing of a high quality TV image which can be live from a camera or stored on a number of the system's 16 digital image stores. The Alpha processing functions are highly interactive with pseudo-analogue control of piecewise linear contrast stretching, colour compositing, tinting, level slicing, maximum emphasis display, ratioing and simple classification. Beta processing implements functions which cannot be easily performed at full TV rates but for which rapid response is essential in an interactive environment. The Beta functions may be one or two dimensional in nature and range from enhancement through multi-spectral classification with complex decision boundaries to spatial (texture) processing and analysis. The third processing mode, Gamma is totally software orientated and is used where it is inappropriate to implement the processing in hardware - e.g., feature optimisation, and classifier training, or where the nature of the data makes software processing the natural function - e.g., ground truth data basing.

The Poster session will present these various modes of interaction by reference to analysis tasks undertaken by the authors and by other users of the equipment. It is currently envisaged that a colour video tape recorder may also be incorporated in both the Poster session and discussion period in order that the symposium's delegates can fully appreciate the speed and form of interaction.

omit

APPLICATION OF REMOTE SENSING TO THE SITING OF THE
WARM SPRINGS DAM, SOMONA COUNTY, CALIFORNIA

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Cranford, New Jersey

ABSTRACT

In 1974, Dames & Moore performed a remote sensing analysis in support of geologic and seismic risk studies for the proposed Warm Springs Dam, Somona County, California, for the U.S. Army Corps of Engineers. These studies were directed to determining the dynamic response of the dam as a function of the regional active fault systems. The remote sensing analysis was undertaken to help establish the regional fault system in the area, the geometry of the faults and the relationship to the regional geology and deformation. A specific question addressed was whether the Rodgers Creek, Healdsburg and Hayward faults were expressed as one continuous feature on the imagery. On the basis of the remote sensing analysis, which utilized Landsat, side-looking airborne radar imagery and aerial photography, it appears that the three faults are not connected, but rather are in an en echelon relationship to one another. Confirmatory field evidence has been gathered in support of this conclusion.

During the course of the investigation, distinct patterns were noticed in the strike of the numerous lineaments detected on the imagery of northern California. A study of histograms of strike vs. frequency of this area shows several dominant peaks. These peaks N65°W, N45°W, N24°E, and N65°E have been previously reported, independently, by Rich and Steel (1974).

The development of a chronological sequence of deformation from the patterns observed in the satellite lineaments has been proposed by Rich and Steel. A similar approach has been used by the author in both tectonically younger and older areas. It appears that this technique is highly productive in unravelling the regional tectonism of an area.

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REMOTE INFRARED SPECTROSCOPY OF
THE EARTH

by

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A B S T R A C T

Increasing interest in the mineralogical application of infrared spectroscopy has recently been shown by geologists, petrologists, and pedologists to use this method as a tool for mineral identification. Several laboratories have conducted studies of the infrared absorption characteristics of minerals and rocks.

Mineralogists are still in the preliminary stage of compiling a library of reference curves that are prerequisite for the correlation of spectral characteristics, molecular lattice-structures and for the identification of unknown minerals and mixtures.

Very little interest has been shown for the infrared reflexion-spectra which correlates to the absorption spectra.

In this investigation the infrared reflexion-spectra of minerals and rocks are used for remote sensing of the targets.

The reflexion-spectra of silicate rocks vary quite significantly from mineral to mineral in the wave length region from 8 to 12 μm . The rock forming minerals like quartz, feldspar, mica and the clay minerals show very different spectral shapes and positions of their maximum of the spectral reflexion.

The presence of a good atmospherical window in that spectral region makes the method of differential-reflexion measurement feasible, for remote sensing application.

As transmitter for infrared radiation we used a tunable CO_2 -Laser working with sufficient power and stability in the spectral band between 9.1 μm and 11.6 μm at more than 100 emission-lines.

Laboratory tests showed the feasibility of the method under different simulated environmental conditions. Because of the very narrow bandwidth of the Laser-emission lines we could obtain reflexion-spectra with extremely high spectral resolution when tuning the Laser stepwise from line to line covering the spectrum between 9.1 and 11.6 μm .

Next the method was tested using a light twin-engined aircraft. As IR-transmitter a 3 Watts tunable CW- CO_2 -Laser was used.

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The reflected Laser-energy was detected with the heterodyne method using the natural Doppler-shift which occurs when the Laser-beam looks some degrees forward in flight direction, as local oscillator.

The signal to noise ratio was still 25 at an altitude of 4.000 ft. The discrimination of different surface materials was already possible

Development of the airborne Laser-system and more fundamental laboratory investigations are in progress.

1.) Introduction

There are many techniques for remote sensing of the earth operating in different portions of the electromagnetic spectrum ranging from the ultraviolet to the microwave region. These techniques have been implemented by systems that are either passive or active. All these systems can detect surface features suited to each individual technique. However, it is still difficult to discriminate different types of rocks and soils. Because of this need an active airborne remote sensing system is developed based on infrared Laser-spectroscopy in the spectral region of the crystal-lattice resonant frequencies (residual rays) of the rock forming minerals.

2.) Laboratory Investigations and Results

To investigate the feasibility of the method and to identify the different parameters of noise, a Laser-spectroscopy facility has been installed.

The system consists of a tunable CO₂-Laser, power supply, Laser-gas-supply, vacuum pump, cooling system, beam forming module, pyroelectric detector, chopper and lock-in-amplifier, radiometer and stripchart-recorder.

The Laser was developed by the Battelle-Institut in Frankfurt, Germany, and is tunable between 9.1 μm and 11.6 μm on abt. 100 emission lines with an average power of 10 W.

The Laser-beam was directed onto the rock-sample. The reflected energy, detected and divided by the total output energy. The Laser was then tuned stepwise from emission-line to emission-line.

The reflected radiation enables to draw curves of the spectral reflectivity with very high spectral resolution.

Ten representative samples were investigated. The influence of surface-structure, temperature and moisture on the spectral shape was investigated tod.

It could be shown that the influence of temperature and moisture is very little. The influence of the surface varied the height of the reflexion peaks, but not their spectral position.

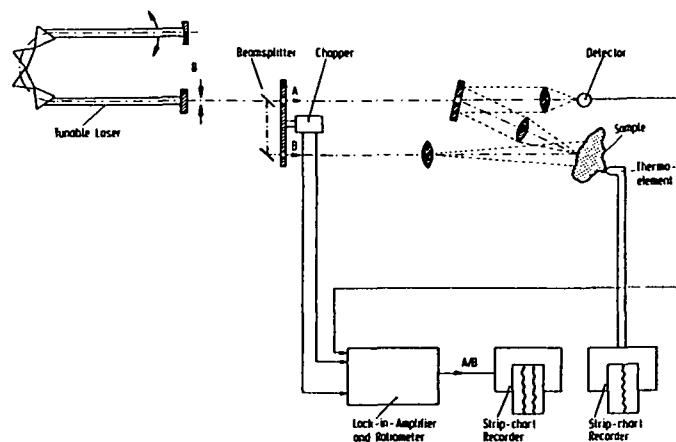


FIGURE 1. SCHEMATIC OF THE LABORATORY MODEL OF THE CO₂ LASER REMOTE SPECTROMETER

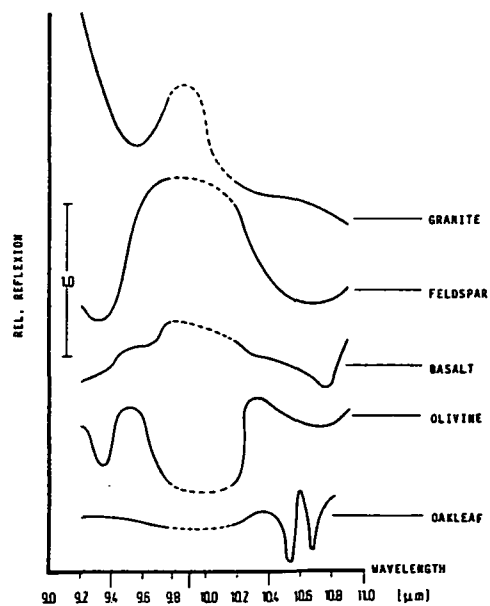


FIGURE 2. RELATIVE REFLEXION VERSUS WAVELENGTH

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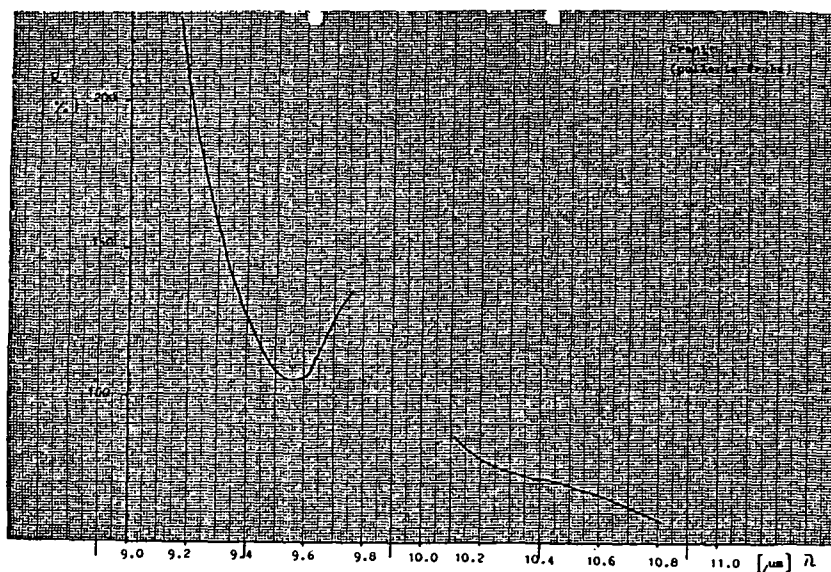


FIGURE 3. RELATIVE REFLEXION OF A POLISHED
SAMPLE OF GRANITE VERSUS WAVELENGTH

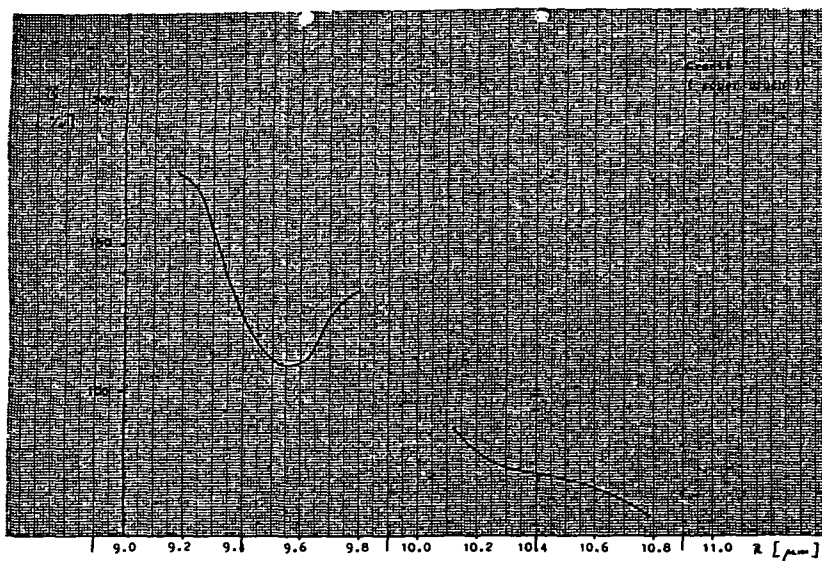


FIGURE 4. RELATIVE REFLEXION OF A ROUGH NATURAL
SURFACE SAMPLE OF GRANITE VERSUS WAVELENGTH

3.) Airborne System development

Commissioned by the West German Federal Ministry for Research and Technology an aircraft-borne measuring system is being developed which is to be used for spectroscopic investigations of the earth's surface and quantitative analysis of air pollutants and natural atmospheric trace gases.

Using tunable CW-IR-molecular Lasers, the method of differential absorption or reflection measurements is applied. The Laser-radiation scattered back from the earth's surface is detected in the aircraft by means of the heterodyne technique.

The measuring system has a weight of 285 kg, a volume of 1.7 m³ and a power input of 1.2 kW. It consists of the optomechanical subsystem, which comprises the Laser head, all optical components (including telescope), the detector system and the instruments for inflight calibration and adjustment, a 19" rack containing the measurement electronics, the data recording system and the Laser supply equipment.

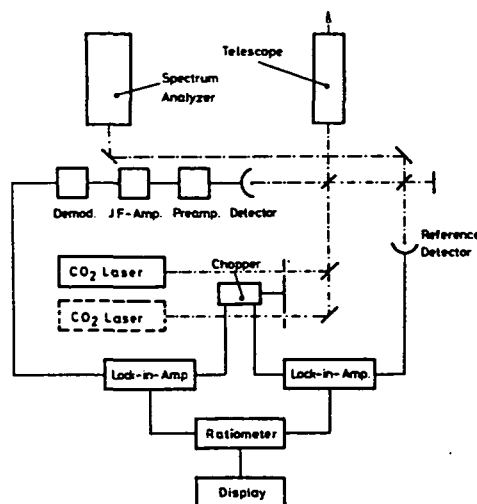


FIGURE 5. SCHEMATIC OF THE AIRBORNE LASER SPECTROMETER

4.) System Installation and Test

The flight tests of the system were carried out in the Dornier 28 Sky servant of the "Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR)" at altitudes between 500 and 4000 ft. The signal to noise-ratio of about 25 , that has been achieved proves the feasibility and superiority of the selected detection method (heterodyne detection using the natural Doppler effect).

Differential measurements have not yet been performed because the functional model for these preliminary flight test was equipped with one Laser only.

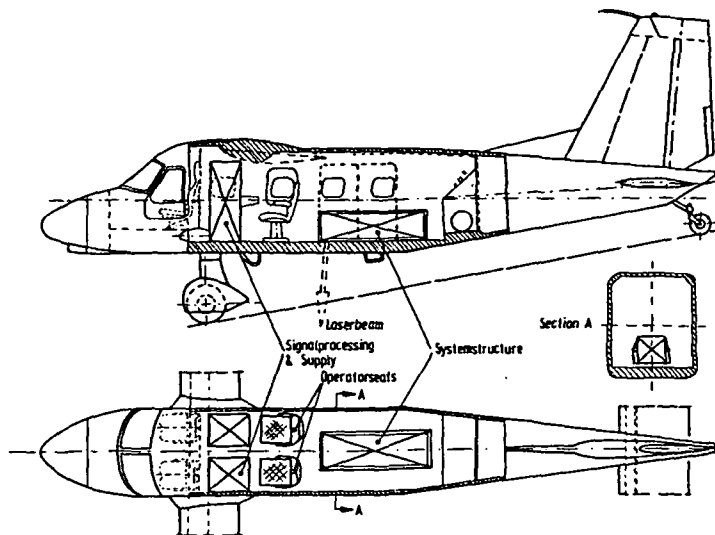


FIGURE 6. CONFIGURATION OF THE AIRBORNE IR LASER SPECTROMETER IN THE AIRCRAFT

Results

The first series of tests of the CO₂ airborne Laser-spectrometer were conducted in September 1976 totalling 27 hours of flight and tests.

First taxiing tests showed good results. The high acoustic and electromagnetic fields of the engines and radio didn't interfere with the Laser detector.

The program consisted of the following items:

- Calibration of telescope focus for altitudes between 500 and 4000 ft.
- Calibration of the deflection angle to produce a constant Doppler-shift.
- Demonstration of the independence from topography to Doppler-shift.
- Documentation of the reflectivity of different surface materials.
- Measurement of Signal to Noise Ratio at different altitudes.

For documentation of the different reflectivity of the surface, photographs were taken. Fig. 7 shows reflexion signal of a forest with signatures of a highway and a clearing.

In later missions in June 1977 two Laser frequencies will be used, making feasible a differential spectroscopic investigation by applying the ratio of the different spectral reflections.

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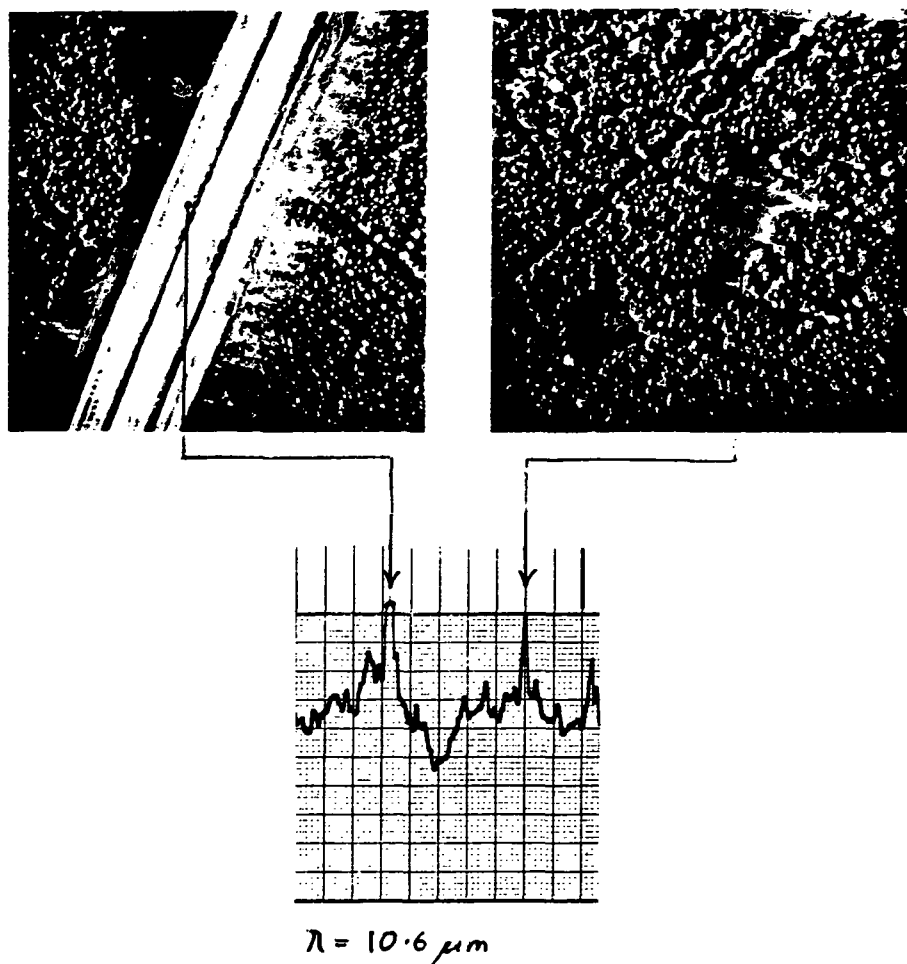


FIGURE 7. DETECTED HETERODYNE SIGNAL
FOREST WITH CROSSING HIGHWAY AND CLEARING

Flight 4	Sept. 13, 1976
Altitude	1500 ft
Speed	50 m/sec
y-axis	10 mV maximum
x-axis	3 inch/min
Integration time	0.25 sec
Length of profile	2 km

Conclusions

An experimental airborne Laser-Infrared-Spectrometer-System based on the interaction of Laser-radiation with the crystal lattice frequencies of the surface minerals is in development.

Laboratory investigations have shown the feasibility of the method. First test flights have shown the feasibility of the heterodyne-detection method of the re-emitted Laser-radiation.

Based on the laboratory and airborne data the following can be concluded:

- Detection of most of the rock forming minerals and clay-minerals with Laser differential measurements is feasible.
- With a two frequency system many geological questions e.g. basic-acid ratio of igneous rocks can be discriminated.
- The geometrical resolution is about 10 m at 10.000 ft altitude.
- The Laser-Spectroscopic System operated reliable in the light aircraft.

Acknowledgements

This work is being sponsored by the German Federal Ministry for Research and Technology. It is being performed by the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR).

The opto-mechanical portion of the experimental airborne Infrared-Laser-Spectrometer was designed and fabricated by the Battelle-Institut, Frankfurt, Germany.

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FIGURE 8. OPTO-MECHANICAL FACILITY TO PERFORM
LASER-SPECTROSCOPIC INVESTIGATIONS OF ROCKS

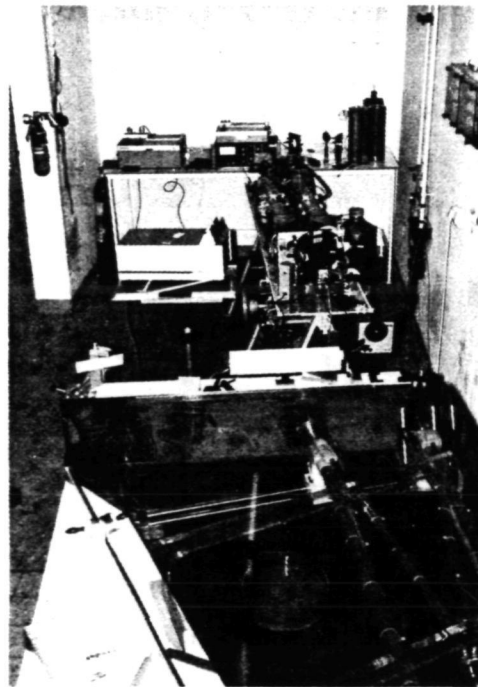


FIGURE 9. IN HOUSE LABORATORY TEST FACILITY.
TUNABLE CO₂-LASER IN FRONT

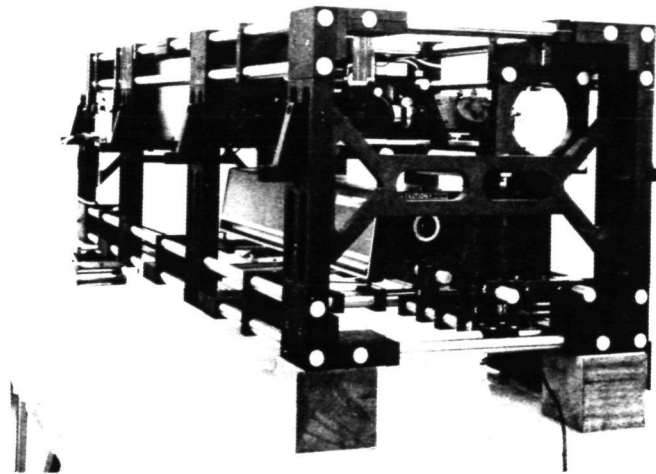


FIGURE 10. MEASURING SYSTEM WITHOUT SHOCK-MOUNTS.
THE VACANT SPACE NEXT TO THE LASER IS RESERVED
FOR THE SECOND CO₂-LASER

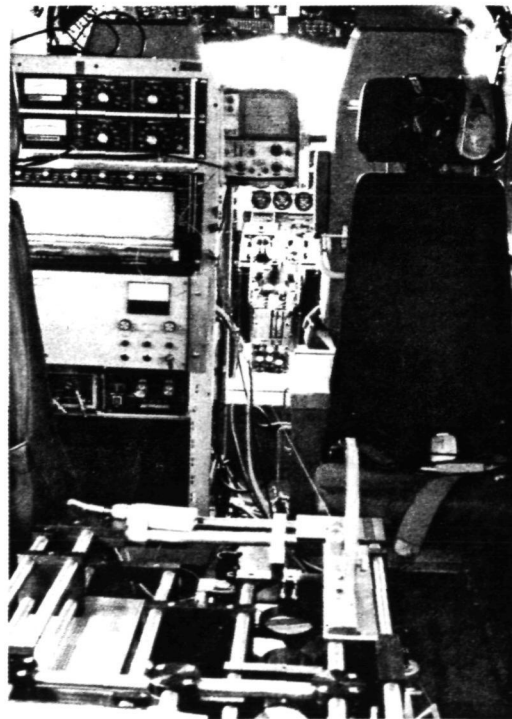


FIGURE 11. A VIEW OF THE CO₂-LASER-IR-SPECTROMETER
MOUNTED IN THE AIRCRAFT

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IMAGE ANALYSIS TECHNIQUES WITH SPECIAL REFERENCE TO ANALYSIS
AND INTERPRETATION OF GEOLOGICAL FEATURES FROM LANDSAT IMAGERY

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ABSTRACT

The principal component analysis enhances the contrast existing between the different cover types present in an imagery. A procedure is presented in this paper with regards to the determination of the principal components. The method is tested for a portion of the LANDSAT imagery pertaining to Anantapur region. Another technique, using the concept of non-linear contrast stretching is defined and developed and carried out on the same imagery. The results are presented as photographs. An interpretation of the geology of the region is derived from these photographs.

1. INTRODUCTION

For processing of LANDSAT imagery usually three distinct techniques are used. One technique is to process the imagery with the help of computers, the second one is to interpret the imagery visually, and the third is a hybrid approach where both automatic and visual interpretation are used.

In computer processing of LANDSAT MSS imagery, there are two steps. The first step is to preprocess the image in order to remove noise, and to improve contrast. The second step is to use the multispectral imagery and classify the cover types. The multispectral classification is very effective for some specific applications like study of landuse, forestry and agricultural inventory. By this classification it is possible to generate thematic maps also (1).

In some applications like in geology, thematic mapping is not of relevance because geological interpretation does not wholly depend on surficial properties and signatures as there is a limited correlation between vegetative and other surface cover and geology. For this reason the interpreter or the photographer usually prefers to study the image itself visually in order not to leave out any significant data or clue. However in some cases visual interpretation of the imagery is not possible because of the low contrast existing between different objects present in the imagery or due to some inherent drawbacks of the photographic recording devices. To avoid these drawbacks various numerical techniques have been used to enhance the satellite acquired data. Some of the commonly used techniques are contrast stretching, band-to-band ratioing and spatial filtering.

In this paper an attempt is made to develop procedures for enhancing the contrast between different objects in MSS imagery. These procedures will be useful for the analysis and interpretation of LANDSAT imagery for geological

applications. As a result of these enhancement techniques, one can obtain certain information which is otherwise not available for visual interpretation.

The basic idea of one of these procedures is the use of the concept of principal component analysis as discussed in (2,3). The method allows for shifting of gray values in the photograph after getting principal components. The analysis depends on the multispectral classification approach but additionally processes the signals so as to achieve better contrast in the picture.

The second procedure described in this paper also uses the multispectral classification technique and evolves a non-linear weighting function to obtain contrast stretching.

2. PROCEDURE FOR ANALYSIS

The method of analysis can be considered in three steps namely the classification of the multispectral data, the computation of covariance matrices and finally the determination of principal components.

2.1. CLASSIFICATION

The first step is to classify the area considered, using the available multispectral data. The classification procedure will identify and separate out the different cover types. An unsupervised classification technique is used for this purpose (4).

2.2. COVARIANCE MATRICES

After completing the classification, the next step will be the computation of the covariance matrices for the different cover types. Because of inherent spectral correlation which the surfacial features of the earth possess in different spectral channels, the covariance matrices will have invariably non-zero elements. The covariance matrix is denoted by C_m where 'm' represents cover type.

2.3. PRINCIPAL COMPONENTS

The last step will be the determination of Principal Components. This step involves the computation of eigen values and the corresponding eigen vectors for each cover type. The eigen values are arranged in the descending order.

The principal components are obtained from the original N spectral bands by the following transformation

$$Y = T_m (X - U_m) \quad (1)$$

where X is the N-dimensional vector of spectral intensities associated with each pixel or ground resolution element,

U_m is the mean vector of dimension N for a cover type 'm',

Y is the vector of principal components, and

T_m is the N x N orthogonal matrix derived from the covariance matrix C_m of each cover type 'm'.

The rows of T_m are the N normalised eigen vectors of C_m .

Using Eqn. (1), new gray values for all the pixels are obtained. The procedure will generate as many number of principal components as there are number of spectral channels. Essentially a new set of pictures are generated from the given four channels by mapping into new four components.

The covariance matrix of the principal components is then $C_y = T_m C_m T_m^t =$

$$\begin{bmatrix} \lambda_1 & 0 & \dots & 0 \\ 0 & \lambda_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \lambda_N \end{bmatrix} \quad (2)$$

where $\lambda_1, \lambda_2, \dots, \lambda_n$ are the variances of the principal component and are also the eigen values of C . It is evident from C that the principal components are uncorrelated and each component has variance less than the previous component.

2.4. NON-LINEAR CONTRAST STRETCHING

In order to enhance the contrast of imagery besides the principal component technique, various techniques have been tried. Bond and Thomas (5) have reported a method that performs contrast stretching. In a similar fashion, but using a different criterion, a technique for contrast stretching is formulated here. In this new gray values for pixels belonging to each cover type are obtained using non-linear stretching over the gray values of the original channels of LANDSAT imagery.

Using the knowledge that a particular pixel belongs to a certain cover type, the gray value of this pixel is modified to a new value, by a weighting factor. This weighting factor, is given by

$$G(j, k) = \frac{U(j, k)}{\sum_{k=1}^n U(j, k)} \quad (3)$$

where $G(j, k)$ is the weighting factor for 'k'th class in the 'j'th band or channel, and

$U(j, k)$ is the mean value of reflectance of the 'k'th cover type in the 'j'th band.

3. IMPLEMENTATION OF THE PROCEDURE

The analysis procedures as described in the previous section are carried out on LANDSAT imagery, pertaining to Anantapur region (I.D.No.2053-04265, 16th March 1975).

3.1. SITE FOR STUDY

A portion of the imagery covering an area of 30 Km x 30 Km is considered for this purpose. The area includes rocks of varied lithological entities like granites, quartzites, limestones and shales, shales and sandstones, and basic igneous intrusives. Penner is the major river flowing through the test site. Central belt of the area trending NNW-SSE comprises hills of varying heights and different rock units. Eastern part of the area is almost plain and shows the presence of basic dykes.

Figures 1 and 2 represent gray values of LANDSAT bands MSS 5 and 7 respectively. Sinuous course of the river Penner can easily be deciphered in Figure 2 than in Figure 1 due to its contrast in gray tone from the surroundings. Central belt of hilly terrain corresponds to limestones and shales and appears more clear in Figure 2. The hill range at the north-western part of the area is perhaps less visible in gray value photographs of bands 5 and 7.

3.2. DATA ANALYSIS

The portion of the imagery has been digitized using the Optronics P-1000 photostan system. The digitizer uses 256 gray levels, gives out one byte of data for each resolution element. The digitized data for each spectral band is stored in a sequence on a CCT. For convenience of handling and analysis, the data is transferred to a magnetic disc.

For analysis purposes, the registration of the imagery in all the bands is an important step. The Sequential Similarity Detection Algorithm (4,6) is used to achieve the correct registration. The analysis of the imagery is performed

in segments, each segment covering an area of 10 Km x 10 Km having 10,000 pixels. Each pixel will have four components corresponding to the spectral intensities in the four channels.

3.2.1. THE PRINCIPAL COMPONENTS. The inherent differences existing between different cover types is utilized in the derivation of principal components.

The data present in the above area is classified using the unsupervised classification algorithm (6). The analysis is carried out in nine segments each of 100 square kilometer. In a typical segment there are six cover types, the statistics of which is presented in Table I. The covariance matrices of all the cover types are then computed. The computed covariance matrix for a cover type is given in Table II.

TABLE I. STATISTICS OF A TYPICAL SEGMENT

Cover Type	Population.	Mean Reflectance				Standard Deviation			
		MSS 4	MSS 5	MSS 6	MSS 7	MSS 4	MSS 5	MSS 6	MSS 7
1	1827	220.7	192.2	183.6	206.1	7.7	10.2	10.9	8.7
2	2981	214.7	173.8	165.0	194.9	7.5	7.6	9.0	7.5
3	2401	207.4	159.7	152.0	185.8	8.4	7.4	8.2	6.9
4	1405	203.9	152.0	139.5	171.3	9.1	10.3	8.4	7.2
5	1098	217.6	187.6	153.2	178.0	7.9	13.6	8.6	9.2
6	288	217.4	196.4	170.4	187.9	20.7	37.7	31.1	26.3

TABLE II. COVARIANCE MATRIX, EIGEN VALUES, AND EIGEN VECTOR MATRIX FOR A COVER TYPE.

COVARIANCE MATRIX	EIGEN VALUES	EIGEN VECTOR MATRIX
$\begin{bmatrix} 56.48 & 7.67 & -7.61 & -2.00 \\ 7.67 & 58.72 & -3.37 & 1.52 \\ -7.61 & -3.37 & 80.54 & -3.74 \\ -2.00 & 1.52 & -3.74 & 56.28 \end{bmatrix}$	$\begin{bmatrix} 84.32 \\ 62.64 \\ 56.82 \\ 48.23 \end{bmatrix}$	$\begin{bmatrix} -0.31 & 0.56 & -0.21 & 0.74 \\ -0.22 & 0.73 & 0.35 & -0.54 \\ 0.92 & 0.33 & 0.12 & 0.16 \\ -0.11 & -0.20 & 0.90 & 0.36 \end{bmatrix}$

The new gray values for all the pixels are then determined using the matrix transformation given by Eqn. (1). The principal components are then obtained and are stored on a magnetic disc in a format of a total segment. These are later used for writing the image on a film transparency in each of the principal components.

Figures 3 and 4 show the prints of first two principal components obtained.

3.2.2. CONTRAST STRETCHING. As explained earlier, an alternate scheme for contrast stretching is to use the information regarding the cover types to which the pixels belong. For this purpose, the gray values of the contrast stretched imagery are obtained by multiplying the original gray values of the pixels by the weighting factor, defined by Eqn.(3).

Figures 5 and 6 show the prints of contrast stretched imagery 1 and 2 respectively.

4. VISUAL INTERPRETATION FOR GEOLOGICAL STUDIES

The visual interpretation discussed here is supported by limited field checks of the area under study. Three major units, namely hills comprising sedimentary rocks, water bodies and dark gray belts corresponding to dykes, are considered for assessing the interpretability of MSS bands 5 and 7, principal components 1 and 2 and contrast stretched imagery 1 and 2.

4.1. INTERPRETATION OF PRINCIPAL COMPONENTS

Using the photographic data from Figures 3 and 4 corresponding to principal components 1 and 2 respectively, a visual interpretation of the geology of the area is carried out. Central belt of limestones and shales is represented in almost uniform gray tone in principal components 1 and 2. River Penner is discernible in principal component 1. Due to the sharp tonal contrast the hill range at the north-western part can be picked up easily in principal components 1 and 2 in comparison to gray value pictures of MSS 5 and 7.

Figure 7 shows the interpretation. A band of quartzite separating limestones and shales from granites is delineated in Figure 7. In the eastern part of the area, dykes running NW-SE are detected in shales. Same can also be seen in principal component 2 where it is less visible. Due to very little gray tone variations, it has not been possible to delineate these units from principal components 3 and 4. For this reason the prints of the principal component 3 and 4 are not included in this paper.

4.2 INTERPRETATION OF CONTRAST STRETCHED IMAGERY

River Penner and the hill range at NW corner appears more clearly in Figure 6. In addition, several hill and sedimentary rocks can be easily picked up on Figures 5 and 6 of the contrast stretched imagery.

Using the photographic data from Figures 5 and 6, a visual interpretation map is generated and is shown in Figure 8. A quartzite hill range separating limestones and shales from sandstones and shales, and basic igneous intrusives are clearly discernible on the enhanced images. These are delineated in Figure 8.

5. CONCLUSION

Two methods are presented to enhance the contrast among different cover types present in an imagery. It is noted that the principal component analysis has compacted all the information content present in the imagery especially to the first two components. The non-linear contrast stretching method has significantly improved the contrast among the cover types of the area under study. Certain geological formation like quartzite, limestones and shales, and basic igneous intrusives are more clearly seen in the principal components and also in the contrast stretched imagery.

ACKNOWLEDGMENT

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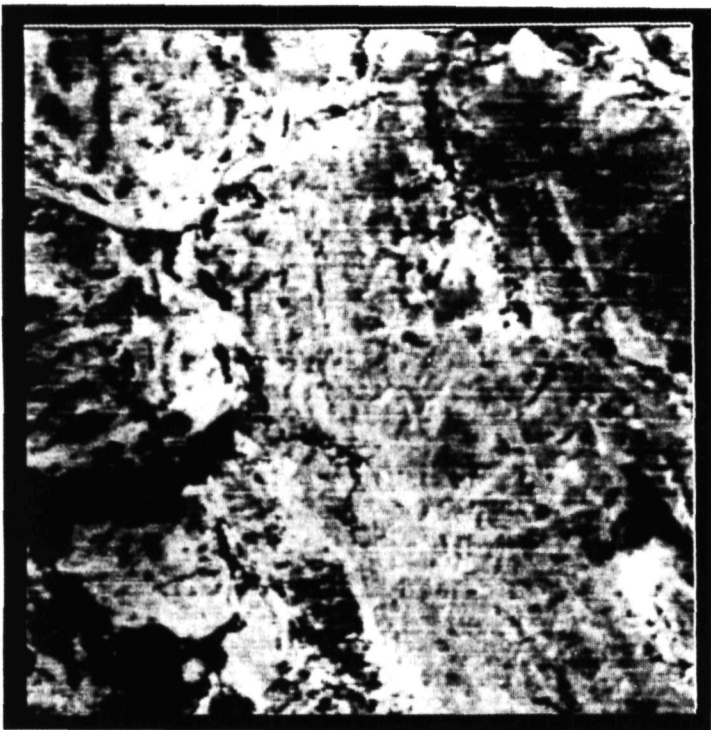


FIGURE 1. GRAY VALUES OF MSS 5.



FIGURE 2. GRAY VALUES OF MSS 7.

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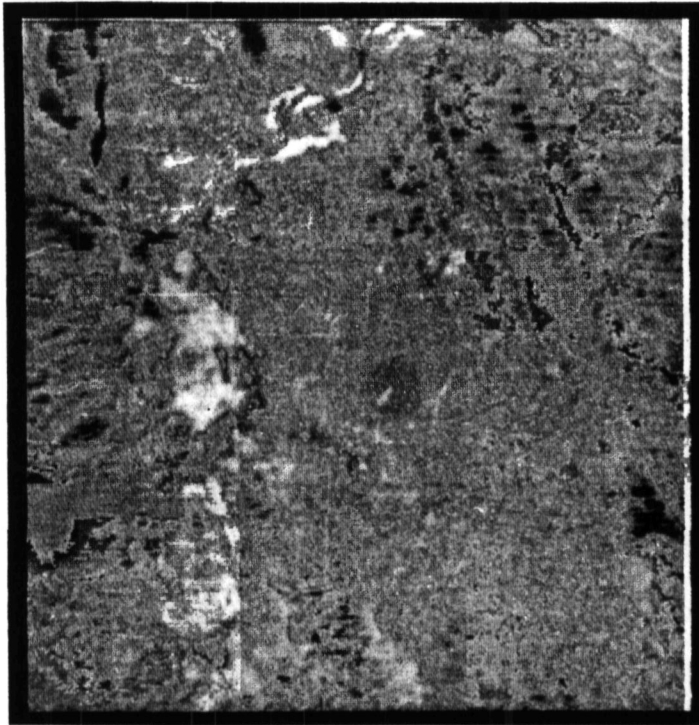


FIGURE 3. PRINCIPAL COMPONENT 1.

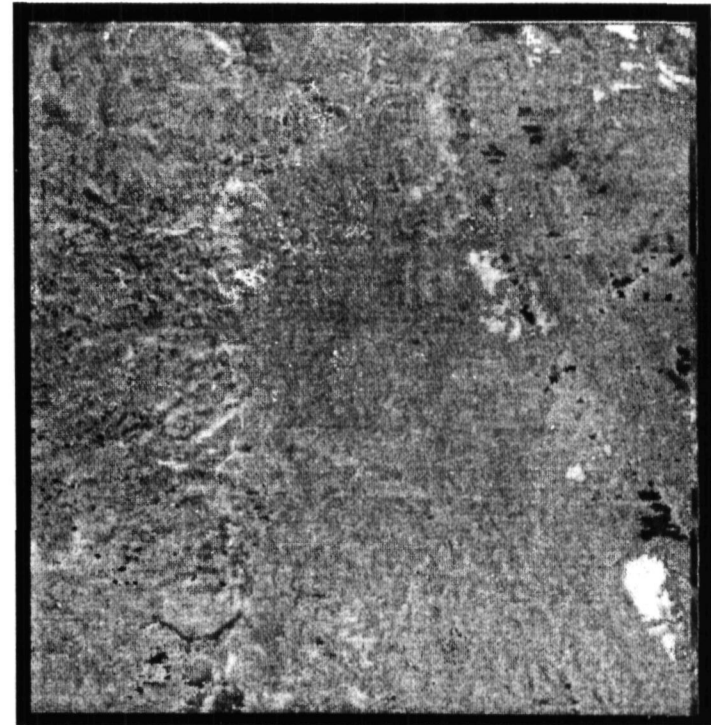


FIGURE 4. PRINCIPAL COMPONENT 2.

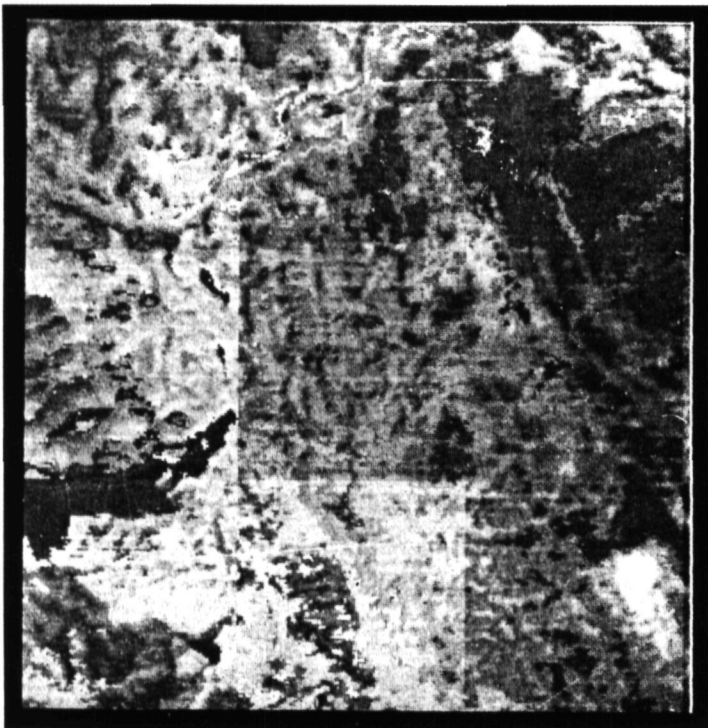


FIGURE 5. CONTRAST STRETCHED IMAGERY 1.

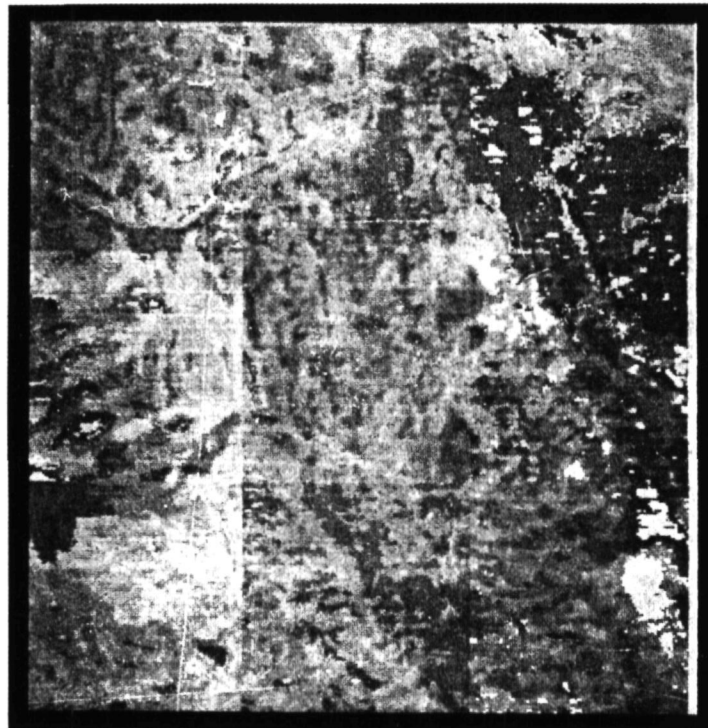


FIGURE 6. CONTRAST STRETCHED IMAGERY 2.

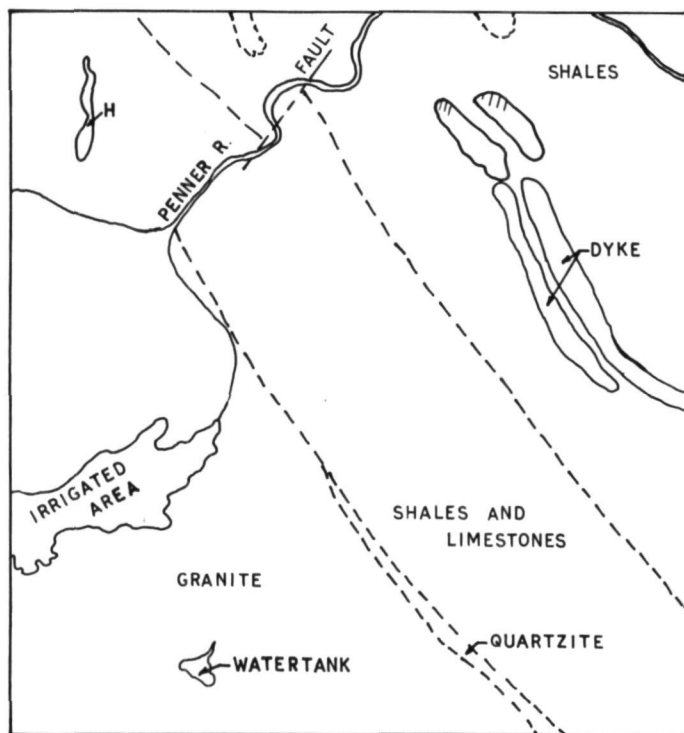


Figure 7 - VISUAL INTERPRETATION FROM PRINCIPAL COMPONENTS

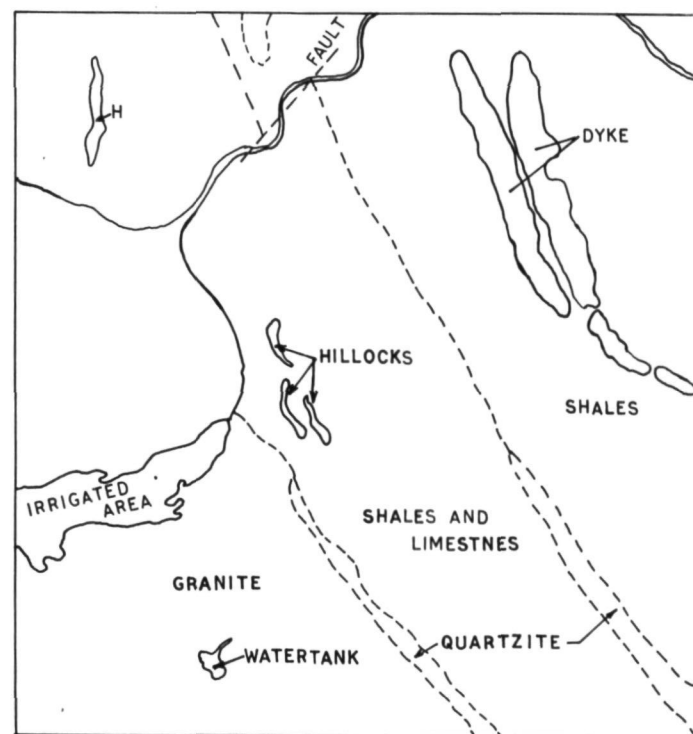


Figure 8 - VISUAL INTERPRETATION FROM CONTRAST STRETCHED IMAGERY

N78-14545

MULTIDATE MAPPING OF MOSQUITO HABITAT

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ABSTRACT

LANDSAT data from three overpasses in 1975 (25 June, 13 July, 9 August) formed the data base for a multirate classification of 15 ground cover categories in the margins of Lewis and Clark Lake, a fresh water impoundment between South Dakota and Nebraska. When scaled to match topographic maps of the area, the ground cover classification maps were used as a general indicator of potential mosquito-breeding habitat by distinguishing productive wetlands areas from non-productive non-wetlands areas. More specifically, the interpretation of the Consolidated Wetlands, Flooded and Transitional classes as permanently-flooded, frequently-flooded and intermittently-flooded, respectively, permitted a breeding potential to be assigned to each class vis-a-vis the preferred breeding habitat of *Culex tarsalis*, a permanent pool species and *Aedes vexans*, a floodwater species. The 12 channel multirate classification was found to have an accuracy 23% higher than the average of the three single date 4 channel classifications. By assuming that the 1.1 acre LANDSAT resolution reflects the dominant tendency within each pixel, the multirate classification map of ground cover categories can be considered a broadbrush indicator of potential mosquito-production and used to plan control programs.

1. INTRODUCTION

The association of certain species of mosquitoes with certain types of vegetation has been recognized for a long time; the association is usually explained in terms of shared ecological niches. For example, in coastal areas the association of *Aedes sollicitans* breeding areas with the salt marsh grasses *Distichlis spicata* and *Spartina patens* has been reported by a number of investigators (Elmore and Fay, 1958; Ferringo, 1953) and exploited to plan mosquito control strategies by mapping the location of the salt marsh grass.

Lewis and Clark Lake, the locale of the present study, is a 50 km long, freshwater, mid-continental impoundment which was created in 1957 when Gavins Point Dam was constructed on the Missouri River between South Dakota and Nebraska. As figure 1 indicates, the portion of the lake between Niobrara, Nebraska and Springfield, South Dakota is narrower and consequently shares the relict floodplain with wetlands, crops and mixed deciduous stands, whereas the wider portion of the lake between Springfield and Gavins Point Dam extends over the floodplain to the bluffs with very few wetlands margins. The location of the study areas reflects this marginal difference and, to some extent, documents it.

In our study areas we were concerned primarily with 2 species of mosquitoes, *Aedes vexans*, a floodwater species, and *Culex tarsalis* which prefers more permanent water habitats. Our principal objective was to define relationships

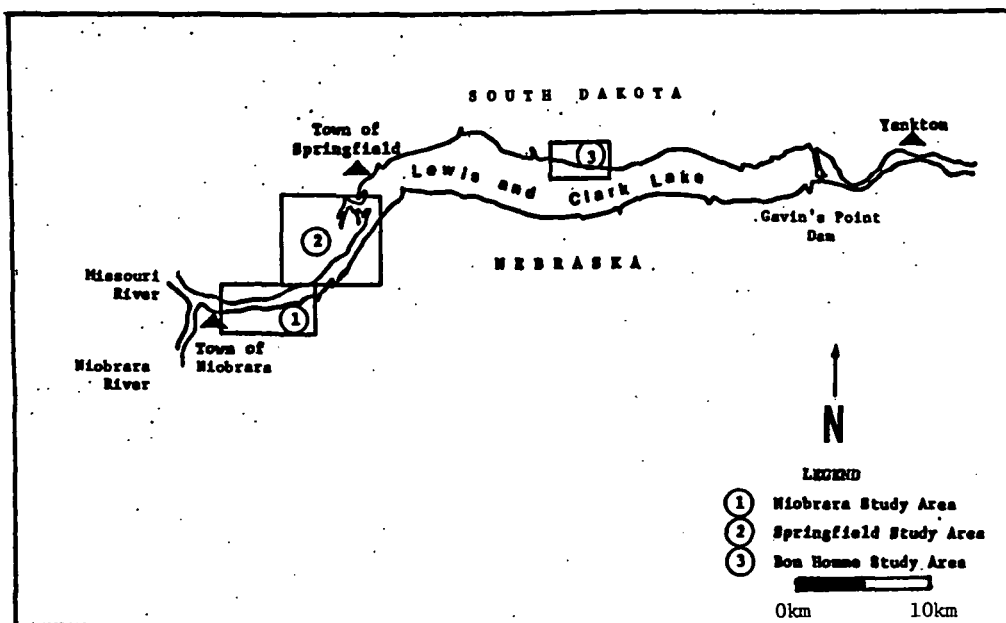


Figure 1. Lewis and Clark Lake and features of interest.

between the breeding habitats of these species and specific plant associations such that a mapping of the vegetative ground cover would serve as an indication of the location of specific mosquito-breeding habitat areas. Mosquito larvae data from collections made by the Water Resources Branch of the Center for Disease Control during the summer of 1975 were used as the reference for the distribution of mosquito-breeding habitat in the study areas. To delineate the vegetation patterns, we could have used conventional mapping techniques such as field transects (Küchler, 1967), interpretations based on black and white aerial photography (Rioux et al., 1963), or interpretations based on aerial color infrared photography (Rohe, 1970); we used multispectral data obtained from LANDSAT for this purpose because of the advantages it offered in terms of availability and repeated coverage of a given area.

LANDSAT data from three dates coincident with the period of larvae collection in the summer of 1975 (25 June, 13 July, 9 August) were digitally-processed to produce single-date land cover classification maps. They were also combined to form a multirate-multispectral land cover classification map of the study areas representative of ground conditions for the entire summer.

What follows is a more detailed description of the attempt to map mosquito-breeding habitat by mapping associated fresh-water wetlands as depicted through a digital, supervised, multirate analysis of LANDSAT data. Application of the remote sensing technique to mosquito habitat mapping over extensive areas such as that surrounding Lewis and Clark Lake should provide a tool for water resources planners and managers to more effectively prevent mosquito problems from developing in impoundment margins.

2. METHODOLOGY

A. Procedures. Computer compatible tapes from LANDSAT-1 and LANDSAT-2 were obtained for three dates in 1975 that coincided with the collection of mosquito larvae. The dates obtained were June 25, July 13, and August 9.

The images for these three dates were rectified, rotated and adjusted to a scale of 1:24,000. A visual fit was made (on a light table) between the images and 7 1/2' quadrangle maps for the area, and all three images were thus registered to each other. Once registration was accomplished, the data from all three dates, for the Lewis and Clark Lake area, were combined onto a single file

such that each pixel was represented by a 12 variable vector (4 LANDSAT bands for 3 dates).

The processing of this combined data tape was accomplished with Colorado State University's LANDSAT Mapping System (LMS). The LMS employs supervised classification using a maximum likelihood algorithm. This system permits the selection of any of the variables on a data tape, so we had the option of classification with data from any one date, or we could use all 12 variables in a multivariate mode.

Three sources of information were used to select vegetation types for classification and the training fields to represent these classes. Initially the data obtained during the 1975 larvae collection program was used to select areas around the lake and vegetation characteristics which were related to mosquito production. Then, color infrared aerial photographs for the area were obtained from the Corps of Engineers, Omaha. We were most fortunate to have photographs taken within two days of the August 9, 1975 LANDSAT overpass. These CIR images were used to select areas having similar radiance characteristics. Finally, three field trips during 1976 (close to the 1975 image dates) were used to obtain on the ground knowledge of vegetation conditions. Using all of this information, and the LANDSAT images themselves, training fields were selected to represent the vegetation and water classes given on Table 1.

Fortunately, the LMS permits the use of irregularly shaped masks to define training fields. This was extremely important for the intermixed, irregularly bounded, natural areas of this project. Of equal importance was the provision of the LMS to delete individual pixels, using statistical criteria, from training data sets. In this way, viable class signatures for the vegetation types noted were obtained. These signatures consisted, of course, of a 12 variable mean vector and covariance matrix.

B. Lewis and Clark Ground Cover Classification Scheme. Colwell (undated) observed that a suitable classification scheme is generally developed as a compromise between what the user considers ideal for his purposes and what the remote sensing analyst finds is consistently identifiable on the imagery he has to work with. Ideally, then, each of the cover types in Table 1, found in the margins of Lewis and Clark Lake, would be identifiable at the species level by means of remote sensing and would have attached to it a coefficient of mosquito breeding potential for the major mosquito species observable in the area. Gabinaud (1975) in fact used ground and aerial surveys to map vegetation species which served as biotic indicators in establishing an ecological chart for studying the distribution of the breeding habitat of two species of *Aedes* in the French Mediterranean lowlands. However, given the resolution of the LANDSAT system, 1.1 acres arranged in a regular rectilinear grid, and the complex, heterogeneous, irregular growth pattern of many of the Lewis and Clark wetlands vegetative species, the ideal solution is not immediately achievable. On the other hand, if the differentiation scale is modified so as to accommodate communities of somewhat larger units than one species, as Gabinaud (1975) occasionally did and Kuchler (1967) recommended, a classification scheme whose vegetation components are consistently differentiable in terms of LANDSAT reflectance is possible.

Table 1 contains the raw material from which such a classification system was ultimately derived for the Niobrara and Springfield areas. The floodplain, in this reach of the river, is the site of wetland units encroaching into areas formerly covered by domestic units and dryland wild flora. In this successional context, transitional units mark the leading edge of the encroaching wetlands whereas flooded units specifically indicate areas where moist ground was observable on the August 9, 1975 color-infrared aerial photos. Figure 2 serves to illustrate these relationships in terms of elevation.

Following the selection of training data, initial tests of class separability resulted in modifications to Table 1 in the form of deletions and combinations of classes. The final set of classes (see Table 2 in the next section) were consistently identifiable from the LANDSAT data, and their areal distribution was indicative of the relative level of the water table. In this manner, mosquito breeding habitat potential could be mapped at a scale consistent with the 1.1 acre resolution of LANDSAT.

C. Single date vs. multidade analysis. Vegetated areas change their characteristic reflectance through time because of phenological or other developments, e.g., the soil component of a corn field's reflectance progressively diminishes from June to August as the plants grow. Several remote sensing investigators have demonstrated that sequential or multidade coverage yields more information, and therefore better identification, than single date coverage (Steiner, 1970; Richardson et al., 1972).

Table 1. Ground cover in margins of Lewis and Clark Lake arranged according to elevation.

H	W	F	T	D	U
WATER	WETLANDS	FLOODED	TRANSITIONAL	DOMESTIC	UPLAND
River Standing	Duckweed Cattails -bleaches -dead trees	Cattails <u>Polygonum</u> Corn Unknown	<u>Polygonum</u> Johnson Grass <u>Kochia</u> Reed Canary Bog Marshcress Foxtail Barley Ragweed Young willow	Corn Alfalfa Oats Wheat Wheatgrass	Mixed Decid. Bluff Grass

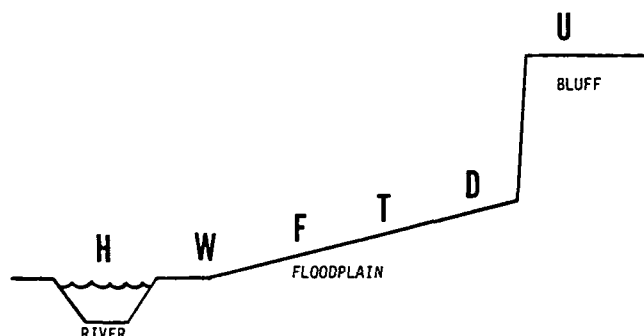


Figure 2. Generalized cross-section across Lewis and Clark Lake and Missouri River floodplain in Niobrara - Springfield areas. Not drawn to scale. Bluff tops are 250 feet (76.2 meters) above river at some locations.

influx of water in the form of increased Culex production (permanent pool species) and decreased Aedes production (periodically-flooded species) as the summer progressed.

3. LANDSAT Classification Results

A. Niobrara. Figures 3, 4 and 5 are ground cover classification maps of the Niobrara study area based on 4 channels of reflectance data from LANDSAT overpasses made on June 25, July 13, August 9, 1975, respectively. Table 2 contains a brief description of the classes which are keyed to the symbols used on these single date classification maps. Noteworthy features on the June map include one area of wetlands north of the river, two areas of wetlands south of the river, a stand of mature mixed deciduous at the eastern border, and apparently, corn-covered islands in the river. On the July map, still water has taken over the islands and much of the wetlands area north of the river, while the two wetlands areas south of the river and the mixed deciduous stand to the east are again evident. In August, the two wetlands

In a wetlands area such as the margins of Lewis and Clark Lake, where the influx of water from upstream dams and the outflow at Gavins Point Dam are the dominant factors affecting water level, it was expected that the multidade approach might be even more effective. For example, a mosquito site which is slightly flooded in June, dry in July, and severely flooded in August would be expected to have a different signature than a site that had a fairly constant water level over the 3 months. A check of reservoir level records and precipitation records at Niobrara, Springfield and Gavins Point Dam indicated a common pattern through the summer of 1975; the reservoir level was not greatly affected by local precipitation and July was a time in which the reservoir level steadily rose to a point where the August impoundment was approximately 0.6 meters higher than in June. Hayes (1977) cited unusual discharges from upstream dams as the reason for the abnormally high reservoir level in August of 1975. Hayes also reported that mosquito larvae collections in the Niobrara-Springfield area reflected the unusual

[illegible][illegible]

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Figure 6. Niobrara ground cover, multidecade classification

areas south of the river and the mixed deciduous stand are still in evidence as contiguous units, whereas the wetlands north of the river and the islands are largely classified as flooded. Many of the variations are explainable in terms of a rising reservoir level and a plant canopy expanding with time.

Figure 6 is a multidecade ground cover classification map of the Niobrara study area based on 12 channels of reflectance data, four channels from each of the three dates. Very noticeably, the patchiness of the single date classifications has disappeared, and well-defined areas of river, wetlands, flooded, transitional, croplands, mixed deciduous and bluff-grass can be discerned. The 12 channel multidecade classification yields a map with better definition than any of the single-date 4 channel maps.

TABLE 2. Legend of symbols used on classification maps of the Springfield and Niobrara study areas.

SYMBOL	CLASS	DESCRIPTION	
W	RVRH	River water	
/	STLH	Still water	
.	CXTW	Cattails	
.	BCTW	Cattails with bleached areas	} consolidated wetlands
.	DWDW	Duckweed	
X	LXGF	Flooded, <u>Polygonum</u> and cattails	
X	XXCF	Flooded, corn	} frequently flooded
T	PXXT	Transitional, <u>Polygonum</u> , ragweed and wild grasses	
Y	YWLT	Young willow and cottonwood	} intermittently flooded
A	ALFD	Alfalfa	
C	QQQD	Corn	
O	OATD	Oats	
W	WHTD	Wheat and wheatgrass	
*	ZZZU	Mature mixed deciduous	
+	FLBU	Bluff grass	

Blank areas are ground cover types different from classes above

In Table 3, areal percentages of selected classes are compared for the June, July, August and Multidate classifications. Noteworthy features are the constancy of River Water and Bluff Grass, the increasing percentages of the Wetlands, Flooded, and Transitional classes through the single date sequence at the expense of the crops and Mixed Deciduous classes, and the averaging effect of the multidate percentages with respect to the single date sequences. The high percentage of Transitional is the one major exception to the Multidate averaging effect and can be explained in part by the large variance in reflectances for the Transitional class.

Table 3. Areal percentages of selected ground cover classes on the June, July, August and Multidate Classifications.

	June	July	August	Multidate
River Water	20.8	20.3	21.5	21.9
Still Water	1.8	9.1	.5	.6
Consolidated Wetlands	18.4	20.8	25.7	22.3
Flooded	11.3	8.0	12.6	9.1
Transitional	5.5	10.5	10.3	21.2
Corn	7.1	3.1	6.1	4.9
Oats/Alf/Wht	14.4	8.5	3.8	4.2
Mixed Decid.	5.4	6.0	4.9	3.7
Bluff Grass	6.5	6.9	6.6	7.1
Other	8.8	6.8	8.0	5.0

Table 4 is a comparison of the accuracy of the single date and the multidate classifications. Seven categories were selected from those used in the classifications and fifteen pixels from each were compared to what was actually found on the ground; the number of each category correctly classified appears in the columns for June, July, August and Multidate. Before discussing the results, certain qualifications need to be mentioned. The fifteen pixels selected were not included in the original training fields. Such a constraint, while yielding an unbiased sample in one sense, often leads to the choice of verification pixels which are not as representative of the category as they could be. Particularly with the complexly-structured wild species this can be a problem because large contiguous non-training groups of pixels are difficult to find. This also limited the classes which could be used for verification. Also, the ground truth, with the exception of the color-infrared aerial photos of August 7, 1975, was gathered in 1976, one year after the period of the LANDSAT imagery. Slight changes, particularly in the complexly-structured categories over the period of a year are a possibility. Finally, a sample size of 15 pixels does not portend great statistical rigor. Table 4, therefore, should be considered a qualified comparison of the accuracy of the single date and multidate comparison.

Table 4 indicates an overall accuracy of classification of 72% for June, 60% for July, 83% for August and 95% for multidate. Thus, August was the most accurate single date classification for the Niobrara study area and the multidate classification was 23% better than the average single date classification. In terms of utility, the results indicate that one single date classification provides an acceptable instantaneous view of ground cover classes with an accuracy as high as 83%, whereas sequential viewing of three single dates permits seasonal changes to be appreciated. The comprehensive multidate classification with an accuracy of 95% provides the best rendition of ground cover in terms of mapping categories and can be used to delineate mosquito-breeding potential in the Niobrara study area.

Table 4. Accuracy of June, July, August and Multidate classifications based on a sample of 15 non-training pixels for each selected ground cover class.

	June	July	August	Multidate
River Water	15	15	15	15
Cattails	15	9	13	15
Flooded	6	4	13	13
Transitional	8	7	7	14
Corn	12	5	10	15
Mixed Deciduous	13	14	14	14
Bluff Grass	4	7	13	14
TOTAL	73	61	85	100
% Correct	72%	60%	83%	95%

AVERAGE SINGLE DATE % CORRECT: 72%

B. Springfield. Figure 7 is the multidate classification map for the Springfield study area. Its data base also was 12 channels, four channels from each of the 3 LANDSAT overpasses selected for the summer of 1975. The ground cover symbols indicate that in this area, the wetlands occupy the northwest margin of the reservoir. Besides pointing out the contrast between the lower river and wetlands areas and the higher bluff areas which are occupied by bluff grass and crops, a distinction is made between river water and the less turbid still water.

C. Bon Homme negative study area. A classification map of the Bon Homme study area on the north margin of the wider portion of Lewis and Clark Lake (see figure 1 for relative location) is shown in Figure 8. This area is in contrast to the Springfield-Niobrara study areas with their significant regions of wetlands cover between the reservoir and the bluffs. Here the transition from reservoir to bluff occurs much more quickly than it did in the Springfield-Niobrara area because the rise in elevation from the reservoir edge is accomplished over a much shorter distance; a slope of 1% is representative of some portions of the Springfield floodplain whereas 30% slopes are typical and near-verticality can be found at the Bon Homme margins of the reservoir. The symbols on the Bon Homme map reflect the rapid transition from reservoir to bluff. Center-pivot irrigation in the form of a circular pattern and a staircase-shaped blank area due to parity errors in the original data tape are evident. Figure 8 was generated only from the four bands of the August 9 LANDSAT overpass. It was felt that in an elevated, stable, agricultural situation, a single-date classification would produce results almost comparable to a multidate classification of a wetlands area. Table 5 is the legend that explains the symbols used in the Bon Homme classification map. Compared to the Niobrara-Springfield areas, the absence of cattails, both flooded classes, still water and young willow classes generally indicates the non-wetland and dominantly upland-agricultural character of the Bon Homme study area.

4. DISCUSSION

In a general sense, the absence of wetlands cover characterizes an area as having a very low percentage of mosquito-breeding habitat sites. A comparison of figures 6, 7, and 8 indicates that the Niobrara and Springfield study areas have abundant potential mosquito breeding sites (the ., X and T symbols stand for the consolidated wetlands, flooded and transitional categories) whereas Bon Homme has very few. In this respect the LANDSAT ground cover classification can be used as a broadbrush indicator of the mosquito breeding potential of an area.



Figure 7. Springfield ground cover, multidecade classification.

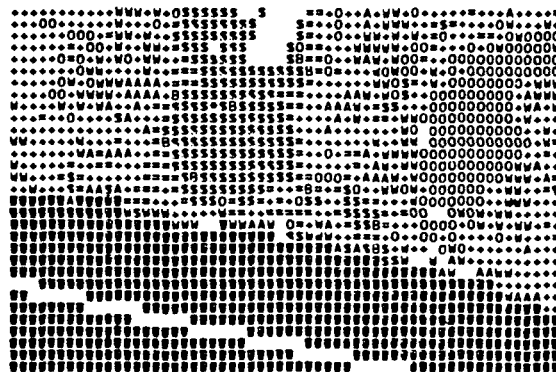


Figure 8. Bon Homme ground cover, 9 August 1975.

Table 5. Legend of symbols used on classification map of the Bon Homme study area.

<u>SYMBOL</u>	<u>CLASS</u>	<u>DESCRIPTION</u>
W	RVRH	River water
B	PMST	Patchy mixed shrubs
A	ALFD	Alfalfa
O	OATD	Oats
W	WHTD	Wheat and wheatgrass
\$	ISGD	Irrigated sorghum
=	PSGD	Poorly-irrigated sorghum
+	FLBU	Bluff grass
		Blank areas are ground cover types different from classes above

It should be noted that other marginal areas of Lewis and Clark Lake are characterized by consistently higher elevations and even steeper reservoir to bluff transitions than at the Bon Homme study area. They have widespread mixed deciduous cover and almost complete absence of wetlands cover classes, except where a few larger streams, with their associated wider valley/lowlands, discharge into the reservoir. Although not shown here, such conditions could also be detected by LANDSAT-derived ground cover classification and used in a preliminary assessment of the mosquito breeding potential over a large region.

The mosquito larvae collection data from 1975 confirm the characterization of the Niobrara and Springfield areas as highly productive and Bon Homme as less productive in terms of mosquito breeding. Table 6 contains the Niobrara, Springfield and Bon Homme collection data for 1975.

Table 6. Fourth instar larvae collections during summer of 1975 at selected study areas in the margins of Lewis and Clark Lake.

	<u>Culex tarsalis</u>	<u>Aedes vexans</u>	<u>TOTAL</u>	Number of collections
Niobrara	8072	5636	13,708	6
Springfield Bottoms	2797	808	3,605	5
Bon Homme	242	21	263	2

Whereas the absence of wetlands cover generally characterizes an area as having a very low mosquito-breeding potential, it is possible within a recognized wetlands area to assign varying degrees of breeding-potential to the constituent wetlands and wetlands-marginal cover types. In the elevational model proposed in Figure 2 for the Niobrara and Springfield floodplains, the three cover types that appear to be located at the levels most conducive to Aedes and Culex larvae production are, in increasing topographic order, the consolidated wetlands (.), flooded (X), and transitional (T) categories which correspond to permanently-flooded, frequently-flooded and intermittently-flooded areas respectively. Given the 1.1 acre resolution of the present LANDSAT system and the view that each pixel classification represents the dominant tendency within the 1.1 acres, it is considered appropriate to use the qualitative terms slight, moderate and problematic to characterize the cover types for mosquito-breeding potential. Because Culex is a permanent pool breeder, we feel that the consolidated wetlands category would be problematic, the flooded category moderate, and the transitional category slight with respect to breeding potential. Because Aedes prefers to breed in periodically flooded areas we would describe the flooded category as problematic, the transitional category as moderate, and the consolidated wetlands category as slight. Control programs aimed at eliminating either Aedes or Culex could therefore use the ground cover classifica-

tion maps (Figures 6 and 7) as guides to the location of potentially problematic breeding sites. With limited funds and the objective of eliminating both Aedes and Culex, the flooded category (X), would be the prime target.

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LATE WISCONSINAN DEGLACIATION OF THE NORTHERN MIDWEST
INTERPRETED FROM A SPRINGTIME LANDSAT COLOR MOSAIC

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SUMMARY

Landsat images of the northern Midwest at different seasons were examined to determine optimal landscape cover conditions for the delineation of Quaternary landscape features. Late April and early May landscape cover conditions best display patterns related to continental glaciation in the Midwestern United States. Different glacial materials often have different soil moisture contents, and differences in soil moisture in the Midwest are most apparent on April and May imagery because vegetative cover is minimal, the ground is thawed, and soil moisture differences are at a maximum and are most apparent at this time of year.

Landscape features resulting from continental glaciation are at a scale that requires analysis of several contiguous Landsat images. A Landsat false-color mosaic at a scale of 1:1,000,000 was constructed at the EROS Data Center from 75 springtime scenes. The mosaic includes North and South Dakota, Nebraska, Minnesota, Iowa, Wisconsin, and part of Illinois--most of the glaciated areas in the Midwest. The most striking landscape features displayed on this mosaic are a series of arcuate patterns that are related to hill and valley landforms, orientation of stream drainage, differences in unconsolidated materials and vegetative cover, and the occurrence of lakes. The lakes commonly occur in linear chains that are aligned along arcuate trends. Some larger lakes are elongated parallel to the arcuate patterns.

The largest lobate pattern can be traced from the Red Lakes area of Northern Minnesota southeastward to Minneapolis and then southward to Des Moines, Iowa. From Des Moines the pattern curves northwestward to the Prairie Coteau and passes near Sheldon, Iowa. The pattern continues northwestward along the Prairie Coteau through the town of Bemis, South Dakota, and can be followed to the northern tip of the Prairie Coteau. Within this larger lobate pattern a series of nested smaller lobate patterns have been delineated which progressively decrease in size and extend from Des Moines to the northern end of the Prairie Coteau. The more obvious lobate patterns show a striking periodicity in spacing. Where the larger lobate patterns are 250 km wide the distance between the nested lobes (measured down the central axis of the lobes) is about 15 to 30 km. Along the axis of the Minnesota River Valley in southwestern Minnesota, the lobate patterns are smaller (less than 150 km wide), and the distance between smaller nested lobes is 30 to 60 km. The nested series of lobate patterns are interpreted as delineating stillstands of the last retreating continental ice mass that receded from the north-central United States beginning about 14,000 years ago.

The relationship between smaller size of the lobes and increased distance between lobes indicates that thickness and areal extent of ice may have been factors that determined the distance the glacier retreated during one major period of rapid melting. At least 17 major periods of retreat are interpreted to have occurred between Des Moines, Iowa, and the northern end of the Prairie Coteau--a distance of 550 km. North of the Prairie Coteau the nested series of lobate patterns are more closely spaced, and some appear to be a distance of

only 10 to 20 km apart. South of this location the continental ice sheet separated into two lobes which extended southward on opposite sides of the Prairie Coteau. The close spacing of the nested lobate patterns north of the Prairie Coteau again suggests that where the distance between stillstands was smaller, a greater thickness and areal extent of ice may have been present. The spacing of the nested lobate patterns suggests periodic climate variations in temperature and precipitation. Under the conditions which probably existed when the ice front was melting rapidly, it is doubtful that organic materials suitable for radiocarbon dating would have been preserved in critical stratigraphic locations.

There appears to be a relationship between the locations of lakes and the lobate patterns. Lakes commonly occur along the lateral margins of the lobate patterns. Apparently at certain times during glacial retreat, lake development was favored because lakes are symmetrically distributed on opposite sides of the same lobate pattern.

Two areas where it is difficult to map lobate patterns occur opposite either side of the series of nested lobes that extend almost to Des Moines. These areas are near Spencer and Mason City, Iowa. In these areas the arcuate patterns have been obliterated, perhaps by extensive fluvial erosion that occurred when the main ice mass in this area melted rapidly. The largest lobate pattern can be extrapolated along an arcuate trend northward from Des Moines, across what has been mapped as the "Iowan Surface" and the "Tazewell Drift". Wisconsinan materials were probably deposited in this area by the last major ice advance here, but were later stripped away exposing older glacial materials.

The EROS Data Center is now producing a master set of computer processed April-May imagery of the United States above latitude 40°. These scenes will be digitally enhanced to improve their interpretability and should be valuable for locating sources of sand and gravel, and peat in the Midwest. The existing mosaic is now being utilized at EDC for analysis of potential sites for groundwater exploration.

NECESSITY TO ADAPT LAND USE AND LAND COVER
CLASSIFICATION SYSTEMS TO READILY ACCEPT RADAR DATA

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ABSTRACT

A hierarchical, four level, standardized system for classifying land use/land cover primarily from remote-sensor data (USGS system) has been proposed for national acceptance by Anderson et al. (1976). The USGS system clearly has been developed for non-microwave imaging sensors such as camera systems and line scanners. Studies have shown that the classification system is compatible with aircraft and space-craft photography and line-scanner imagery obtained at various altitudes.

The USGS system commonly is not compatible with the land use/land cover classifications at different levels that can be made from radar imagery, and particularly from synthetic-aperture radar (SAR) imagery. The lack of compatibility exists because of the special capabilities of radar, particularly SAR, for data gathering that are not duplicated by the imaging optical sensors. The use of radar imagery for classifying land use/land cover at different levels is discussed, and a possible revision of the USGS system to more readily accept land use/land cover classifications from radar imagery is proposed.

1. INTRODUCTION

Many different land-use classification systems currently are in use in the United States. Some of the classification systems are constructed for specific disciplines such as urban planning, agriculture, forestry, etc. A standardized general classification system for many different disciplines is needed.

During the past forty years it has been successfully demonstrated that remotely-sensed data is useful for land-use and land-cover mapping (Anderson et al., 1976). Several land-use classification systems are designed for or amenable to use with remote-sensing techniques. However, remote-sensing data is not compatible with many of the presently-used land-use classification systems for at least two reasons: (1) In many instances remote-sensing data provides information concerning only the land cover and not the land use. The presently-used systems generally differentiate their categories on the basis of land use, not land cover. The terms land use and land cover are not necessarily synonymous. According to Clawson and Stewart (1965), land use refers to "man's activities on land which are directly related to the land." Burley (1961) believes that land cover refers to "the vegetational and artificial constructions covering the land surface." (2) Many of the presently-used systems classify the land use in a very detailed manner, particularly in their higher levels of categorization. While various types of remote-sensing data can provide

detailed land use/land cover information, the data commonly do not provide the very detailed information needed for certain urban land use classification systems, etc.

As Anderson et al. (1976) point out, there are several problems in using any particular system to classify land use/land cover, whether or not the system is specifically designed to accept remote-sensing data. These problems include: (1) Some uses of the land cannot be directly related to the type of land cover. (2) There may be multiple uses occurring on a single parcel of land. The multiple uses may occur simultaneously or alternately. (3) There commonly are vertical arrangements of land uses above or below the actual ground surface. Mineral or petroleum deposits may be extracted underground, electrical transmission lines cross areas of various urban and rural land use, etc. (4) The size of the minimum area that can be classified as to land use or land cover.

Clearly what is needed is a nationally-accepted standardized system for classifying land use/land cover from data obtained primarily by remote-sensing techniques, but reasonably compatible with present classification systems. The land use/land cover classification system of Anderson et al. (1976) is intended to be the needed system, but unfortunately it is not always compatible with radar data. For convenience, the system of Anderson et al. (1976) is hereafter called the USGS system.

2. THE USGS SYSTEM

The USGS system for classifying land use and land cover from remotely-sensed data is discussed by Anderson et al. (1976) in USGS Professional Paper 964. The professional paper is a revision of an earlier classification system described in USGS Circular 671 by Anderson, Hardy, and Roach (1972). Types of land use and land cover identifiable primarily from remote-sensor data are the basis for organizing the USGS system (Anderson et al., 1976). The USGS system is specifically designed to be receptive to data obtained from satellite as well as aircraft remote sensors. It is intended to be a national system, and it is becoming accepted by the federal government and various states as the system to be used for classifying land use/land cover from remote-sensing data. Therefore, it is extremely important that the necessary revisions in the USGS system be made as soon as possible.

The USGS system classifies land use/land cover in four distinct levels of categorization, with Level II being the "basic" level of classification. As the levels of classification increase from Level I through Level IV, the land use/land cover classifications that can be made become more detailed and the areas that can be classified a specific Level III or IV category commonly become smaller; these are desirable features of the classification system. The system is a hierarchical one in that the more detailed higher-level categories (Levels III and IV) are collapsible into the more generalized lower-level categories (Levels I and II).

Uniformity in categorization is intended only at the first and second levels. Land cover is the primary basis for categorization at the first and second levels. Land use is the primary basis for categorization at the first and second levels, but land use is also a basis for categorization at the second level. The categories of Levels I and II of the USGS system are discussed in Anderson et al. (1976).

The USGS system is intentionally left open-ended so that various governmental agencies can have flexibility in developing more detailed land-use classifications at the third and fourth levels. This allows the agencies to meet their particular needs and at the same time remain compatible with each other and the national system. Land use generally is the primary basis for categorization at Levels III and IV.

The USGS system has been developed on the assumption that different remote sensors will provide data for different levels of classification. However, the USGS system clearly has been developed for non-microwave imaging sensors, such as camera systems and line scanners. For these optical sensors the scale and resolution of the imagery decrease with range, which is altitude above ground. Anderson et al. (1976) state that the USGS system has been developed "...because different sensors will provide data at a range of resolutions dependent upon altitude and scale. In general, the following relations pertain, assuming

a 6-inch focal length camera is used in obtaining aircraft imagery.

Classification Level	Typical Data Characteristics
I.....	LANDSAT (formerly ERTS) type of data.
II.....	High-altitude data at 40,000 feet (12,400 m) or above (less than 1:80,000 scale).
III.....	Medium-altitude data taken between 10,000 and 40,000 ft (3,100 and 12,400 m) (1:20,000 to 1:80,000 scale).
IV.....	Low-altitude data taken below 10,000 ft (3,100 m) (more than 1:20,000 scale)."

In the above table, Anderson et al. (1976) say that the remotely-sensed data for Level III classification typically will be at 1:20,000 to 1:80,000 scale. Later they state that remotely-sensed Level III data commonly will be obtained at scales of 1:15,000 to 1:40,000. Substantial amounts of supplemental information are needed at Level III and much more supplemental information is used for Level IV classification (Anderson et al., 1976). Manual methods of imagery interpretation were assumed in determining the different categories and levels of the USGS system.

In his discussion of the USGS system, Avery (1977) also indicates that the system has been developed for optical scanners. Avery states that "Each sensor provides a degree of image resolution that is dependent upon flight altitude and effective focal length (or scale). For example, assuming a focal length of 15 cm, the following flight altitudes and image scales would be appropriate when manual (nonautomated) interpretation is anticipated.

Classification level	Sensor platform or altitudes	Approximate range of image scales
I	Earth satellites	1:500,000 to 1:3,000,000
II	9,000 - 12,000 m	1:60,000 to 1:80,000
III	3,000 - 9,000 m	1:20,000 to 1:60,000
IV	1,200 - 3,000 m	1:8,000 to 1:20,000

It should be stressed that the foregoing recommendations are approximate guidelines and not absolutes. With future technological advances, such tabulations will need to be revised." Notice the difference between Avery and Anderson et al. (1976) in the anticipated range of altitudes of the optical sensors in obtaining data for classification at Levels II and III, and particularly Level II.

As the altitude of optical remote sensors increases, the level of land use/land cover classification that can be accomplished drops. It generally is possible to do only Level I and Level II classifications from satellite or high-altitude photography and line-scanner imagery. In contrast, Level IV classification generally is done from low-altitude photography and line-scanner imagery at a scale larger than 1:20,000. Therefore, one should not expect to do both Level I and Level IV classifications from the same small-scale photography or line-scanner imagery, but Levels I through IV classifications could be done from the same large-scale photography or imagery.

It is not surprising that the USGS system has been developed for use with optical sensor data, considering that most remotely-sensed land use/land cover data has been obtained by such sensors. On the other hand, different types and amounts of land use/land cover data are obtained by the various remote sensors because of their different capabilities for data gathering. Thus it is unfortunate that the USGS system has not been developed to take into account the special characteristics of radar imagery for land use/land cover classification.

3. THE USE OF RADAR IMAGERY FOR LAND USE/LAND COVER CLASSIFICATION

With the proper power supply, the resolution of synthetic-aperture radar (SAR), particularly in the range direction, is essentially independent of range and radar wavelength. SAR commonly is used on aircraft and is the type of

radar to be used on spacecraft. The presently unclassified resolution of radar used in the United States is approximately 1.6 m (range) x 2.2 m (azimuth).

The parameters that most significantly affect the radar return from terrain features include surface roughness, topography (including orientation and slope of surfaces), complex dielectric constant of the feature, object geometry, type and extent of vegetation, and the incidence angle, wavelength, and polarization of the transmitted radar energy. Changes in these parameters can greatly change the return from similar features, even with the same imaging conditions. However, studies done using either single- or dual-polarized radar imagery have shown that the level of land use/land cover classification that can be done from radar imagery is primarily a function of the wavelength, polarization(s), and resolution of the reflected radar energy, and the orientation of the feature (particularly a linear feature) to the radar look direction. Therefore, considering that the resolution of a SAR system remains constant with increasing altitude, the level of land use/land cover classification that can be done from radar imagery is independent of the range from the radar to the terrain.

Furthermore, the level of land use/land cover classification that can be done commonly is independent of the scale of the radar imagery. Levels I through III or IV classifications are possible from the same small- or medium-scale radar imagery. The special imaging capabilities of radar, such as producing high-intensity point returns from individual features, bright linear returns from linear features, areas of no-return, etc., aid in delineating spot locations and areas of certain categories of Levels III and IV on small-scale radar imagery. The presence or absence of bright point or linear returns on radar imagery generally is a function of both the orientation of the feature to the radar look direction and the polarization of the reflected radar energy.

The USGS system has been developed on the assumption that different remote sensors will provide data for different levels of classification. Anderson et al. (1976) state that there is little likelihood that any one sensor or system will produce good land use/land cover data at all altitudes. Both beliefs are wrong as far as SAR is concerned. However, it is true as Anderson et al. (1976) point out, that as the more detailed levels of categorization are used (Levels III and IV), more dependence must be placed on higher resolution remote-sensor data. High-resolution data can be obtained by SAR at all altitudes, but high-resolution data can be obtained by civilian optical remote sensors only at low and medium altitudes.

In discussing the four levels of classification of the USGS system, Anderson et al. (1976) state or imply that generally as the level of classification goes from Level I to Level IV, the altitude of the remote sensor decreases, the scale of the imagery becomes larger, and the resolution of the remote-sensor system markedly improves. This obviously is not necessarily true as far as a SAR system is concerned. Therefore, the USGS system not only needs to be revised to readily accept the land use/land cover classifications at different levels that can be made from radar imagery, but the discussion of the classification criteria needs to be re-written to emphasize: (1) The differences at the different levels of classification in the typical characteristics of the data obtained by imaging optical remote sensors and imaging microwave sensors. (2) That the basis of the USGS system is that in going from Level I to Level IV, the land use/land cover classification that can be done from all types of remote-sensing data just becomes more detailed.

4. POSSIBLE REVISION OF THE USGS SYSTEM

The USGS system and its predecessor system have been tested and found to be compatible with aircraft and spacecraft photography and line-scanner imagery, including thermal infrared imagery (Brown and Holz, 1976), obtained at various altitudes. In fact, the land-use classification system proposed in USGS Circular 671 was revised in order to incorporate the results of extensive testing of that system. However, the USGS system is not necessarily compatible with land use/land cover classifications at different levels that can be made from radar imagery. This lack of compatibility for urban areas has been pointed out by Bryan (1974, 1975). Anderson et al. (1976) anticipate that the USGS system may need modification in the future, particularly for use with automatic data analysis.

A possible revision of the USGS system so that it will readily accept land

use/land cover classifications made from radar data is given in Table 1. Other revisions of the USGS system certainly are possible and are encouraged in order that the best possible revision of the system in terms of radar data can be constructed and tested.

Revision of the USGS system is done only at Levels I and II, with most of the revision involving the present Level II categories of Urban or Built-up Land. New as well as revised Levels I and II categories are suggested to accommodate the types of land use/land cover data that can be obtained from radar imagery, and these categories are briefly described. Levels III and IV categories are still to be determined locally. However, at these levels the detail seen on radar imagery may be greater than that seen on imagery obtained by optical remote sensors.

Many of the features of the suggested new and revised categories may "look" different on radar imagery, and in some instances may not be detected or identified, depending upon the orientation of the feature to the radar look direction and the wavelength and polarization of the radar imagery being interpreted (see Lewis, 1968; Lewis, MacDonald, and Simonett, 1969). The features that may "look" different or may not be detected or identified on radar imagery include railroads, power transmission lines, and microwave transmission towers.

1. Urban or Built-up Land

The description of this category is the same as that given by Anderson et al. (1976) except that transportation, power, and communications facilities are taken out of this category and made into separate Level I categories. Brown and Holz (1976) have suggested doing something similar after a study of thermal infrared imagery.

11. Residential

Essentially the same description for this category as that of Anderson et al. (1976). However, housing areas on military bases or at colleges and universities, living quarters for laborers near a work base, or lodging for employees of agricultural field operations or resorts may be readily discernable on radar imagery. If so, these areas should not be placed within the Industrial, Agricultural, or Commercial and Services categories.

13. Industrial

Electric-power generating stations, and oil refineries and tank farms are taken out of this category as defined by Anderson et al. (1976) and put into new Level II categories.

2. Transportation

The transportation routes and facilities must be mappable on the imagery as separate features distinct from other land uses. Level II categories include Highways, Railroads, Airports, and Ports and Marinas.

21. Highways

Following Anderson et al. (1976), the highways include rights-of-way, interchanges, highway bridges, and service and terminal facilities. In urban regions, highways generally consist of more than two lanes.

22. Railroads

Rail facilities include stations, parking lots, roundhouses, repair and switching yards, and related areas, as well as overland track and spur connections, and railroad bridges.

23. Airports

All airports regardless of their size, use, and runway materials are included in this category. Airport facilities include the runways, intervening land, terminals, service buildings, navigation aids, fuel storage, parking lots, and a limited buffer zone (Anderson et al., 1976).

TABLE 1. Possible revision of the USGS system to readily accept land use/land cover classifications made from radar data.

Level I	Level II
1 Urban or Built-up Land	11 Residential. 12 Commercial and Services. 13 Industrial. 14 Industrial and Commercial Complexes. 15 Mixed Urban or Built-up Land. 16 Other Urban or Built-up Land.
2 Transportation	21 Highways. 22 Railroads. 23 Airports. 24 Ports and Marinas.
3 Utilities	31 Electric Power Generation. 32 Refineries. 33 Other Utilities. 34 Utility Transmission Networks.
4 Communications	41 Microwave and Media Transmission Areas. 42 Communication Transmission Networks.
5 Agricultural Land	51 Cropland and Pasture. 52 Orchards, Groves, and Vineyards. 53 Nurseries and Ornamental Horticultural Areas. 54 Confined Feeding Operations. 55 Other Agricultural Land.
6 Rangeland	61 Herbaceous Rangeland. 62 Shrub and Brush Rangeland. 63 Mixed Rangeland.
7 Forest Land	71 Deciduous Forest Land. 72 Evergreen Forest Land. 73 Mixed Forest Land.
8 Water	81 Streams and Canals. 82 Lakes. 83 Reservoirs. 84 Bays and Estuaries.
9 Wetland	91 Forested Wetland. 92 Nonforested Wetland.
10 Barren Land	10-1 Dry Salt Flats. 10-2 Beaches. 10-3 Sandy Areas other than Beaches. 10-4 Bare Exposed Rock. 10-5 Strip Mines, Quarries, and Gravel Pits. 10-6 Transitional Areas. 10-7 Mixed Barren Land.
11 Tundra	11-1 Shrub and Brush Tundra. 11-2 Herbaceous Tundra. 11-3 Bare Ground Tundra. 11-4 Wet Tundra. 11-5 Mixed Tundra.
12 Perennial Snow or Ice	12-1 Perennial Snowfields. 12-2 Glaciers.

24. Ports and Marinas

Port areas include the docks, shipyards, drydocks, locks, and waterway control structures (Anderson et al., 1976). Marinas include docks and supporting service facilities.

3. Utilities

Areas used for the processing, treatment, or generation of water, gas, oil, or electricity are included in this category, as well as the long-distance networks used to transport the products of the processing, treatment, or generation. Level II categories include Electric Power Generation, Refineries, Other Utilities, and Utility Transmission Networks.

31. Electric Power Generation

These are the areas and facilities used for generating electric power and include hydroelectric, nuclear, and fossil fuel power plants. Electric power generation facilities utilizing wind and solar energy will also be included in this category.

32. Refineries

Includes all the facilities actively involved in refining petroleum, as well as the facilities at the refinery used in delivering the petroleum and tank farms used to store the refined products.

33. Other Utilities

These are the utilities not involved in generating electric power or refining petroleum. Includes water treatment facilities, telephone facilities, etc.

34. Utility Transmission Networks

Includes all overland and underground facilities used to transport petroleum, electric power, telephone conversations, water, etc. from the areas of processing, treatment, or generation to where the petroleum, electric power, etc., is used by consumers. Pumping stations, electric substations, and other similar facilities used along the route and at the terminus of the route are included in this category. Although Utility Transmission Networks generally go through areas of other land use/land cover, they commonly constitute the dominant use of the land, particularly when the network occurs above ground.

4. Communications

Includes facilities (buildings, antennas, etc.) used to transmit airwave communications and the transmission networks used to carry the communications long distances. Level II categories include Microwave and Media Transmission Areas and Communication Transmission Networks.

41. Microwave and Media Transmission Areas

These are the areas from which the airwave communications originate. Generally, the radar, radio, or television antennas are the most identifiable features of these areas.

42. Communication Transmission Networks

Includes all facilities used to carry the communications long distances overland. The networks consist primarily of relay stations and associated antennas.

5. Agricultural Land

The Level II category of the USGS system, 22. Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas, is broken down into two Level II categories, 52. Orchards, Groves, and Vineyards, and 53. Nurseries and Ornamen-

tal Horticultural Areas, in this proposed revision of the USGS system. The descriptions of the features of the new Level II categories 52 and 53 are the same as those given by Anderson et al. (1976).

5. SUMMARY

Limited studies have shown that accurate land use/land cover classification at different levels can be done from single-wavelength, either single-or dual-polarized radar imagery (Lewis, 1968; Lewis, MacDonald, and Simonnett, 1969; Henderson, 1977) and from multispectral radar imagery (Bryan, 1975) by untrained individuals who had little or no previous experience either interpreting radar imagery or with the area(s) being interpreted. These studies, although certainly not definitive, show that there are no large-scale interpreter limitations on the land use/land cover classification of radar imagery. There is an extremely good chance that when radar imagery, particularly multispectral radar imagery, is routinely available from space shuttle and satellites in the 1980's and beyond, that, because of three reasons, we may not be able to effectively use the imagery for land use/land cover classifications: (1) We will not have acquired enough signature data indicating what certain land use and land cover categories should look like on radar imagery of different wavelengths and polarizations. (2) We will not have trained enough human interpreters and will not know how to accurately computer classify the data. (3) The land use/land cover classification system(s) for use with remote sensor data will not readily accept the types of land use/land cover data that can be obtained by radar.

There certainly is no need to develop a new land use/land cover classification system especially for radar data. Basically, what is needed is to revise the descriptions of the characteristics of the various levels of land use/land cover classification to point out that the levels differ in terms of detail of classification and not necessarily in differences in scale or resolution of the imagery or range of the sensor from the terrain. The revision of the USGS system to readily accept data obtained from radar imagery should be done now while the classification system is still in its formative stages.

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APPLICATION OF AIRBORNE INFRARED TECHNOLOGY TO MONITOR BUILDING HEAT LOSS

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SUMMARY

During the 1975-76 winter heating season ERIM conducted studies to test the application of airborne infrared technology to the requirements for energy conservation in buildings. Quantitative airborne data of the City of Ypsilanti, Michigan were collected and processed to identify roof temperatures. A thermal scanner was flown at an altitude of 1,200 feet with two thermal bands 8.2-9.3 μm and 10.4-12.5 μm recorded by an analog system. Calibration was achieved by standard hot and cold plates. Using a thermal model to interpret ceiling insulation status, environmental factors were found to influence the relation between roof temperature and insulation. These include interior and sky temperatures, roofing materials, and the pitch and orientation of the roof. A follow-up mail survey established the ability to identify insulated and uninsulated houses from the airborne infrared data.

INTRODUCTION

Increasing costs of energy have led to major reexamination of procedures for insulation, and maintenance of existing buildings. As part of this re-analysis, the Environmental Research Institute of Michigan (ERIM) has investigated the use of an aerial thermal scanner system to evaluate building insulation characteristics [1].

Alternatives available for determining the adequacy of building insulation within a community are limited. Fuel use data is difficult to interpret and lack of knowledge about insulation and number of buildings within a community makes direct survey techniques impractical. In addition, actual presence of insulation within a building is often not a true indication of its adequacy. Defective insulation, settling, and aging result in significant changes in thermal transmission properties. Thus, a method is sought which will rapidly yield heat-loss information about large numbers of buildings in order to identify effective insulation characteristics as well as roof areas with critical heat loss. Some aerial infrared survey work of cities have been conducted such as the study performed by CENGAS, a Nebraska gas utility, in February 1975 [2]. These surveys produced black and white photographic images which were largely qualitatively interpreted. The methodology employed in the present study used a one-dimensional heat transfer model of a gable roof system to aid the interpretation of results.

AERIAL THERMAL IMAGERY

Aerial thermal imagery was collected using the thermal IR channels of ERIM's 12-channel multispectral scanner system. The two thermal bands simultaneously recorded were in the 8.2-9.3 μm and the 10.4-12.5 μm wavelength ranges. A visible band was also recorded but because the data were recorded at night only street lights and building exterior lights were recorded.

The two cryogenically cooled radiation detectors were digitized and recorded on magnetic tape for later playback. The scanner optics record two temperature reference plates internal to the scanner. These reference plates were maintained at carefully controlled temperatures for later temperature calibration of the thermal imagery. A 70 mm film strip print was produced from a continuous tone video image. Because these data are initially recorded on magnetic tape, electronic editing, calibration, and enhancement procedures can provide a number of possible final image products.

The airborne thermal survey was completed during the evening of November 23, 1975. Surface temperature was reported to be -5°C with a wind speed of 3 knots/hour. Flight data was obtained near midnight under clear sky conditions. The flight data consisted of three-four mile flight lines over Ypsilanti and two-three mile flight lines over Ann Arbor at an altitude of 1,200 feet. A map of the area covered is shown in Figure 1.

Aerial data were interpreted using two types of imagery -- continuous tone images indicating relative temperature differences by variations in contrast (or graytone) and black and white temperature "slices". Examples of these two types of imagery are shown in Figure 2.

To produce the calibrated "slices", the aerial data were quantized into discrete signal levels representing 16 "apparent" temperature ranges from 10° to 40°F . These were individually imaged and photographed such that all portions of the scene having the same temperature range were highlighted, while all surface temperatures outside that range appear black. Thus, 16 black and white strip-prints provide quantitative evidence of building roof temperatures and their variations. By producing a series of these temperature slices, each with a different increment, the full temperature range of the scene is represented. Surface water and vegetated areas generally are warmer than the roof surfaces. Roof temperatures are generally colder than air temperatures on clear nights due to the net transfer of heat by radiation to the cold sky.

It must be noted that these are "apparent" temperatures. For most surfaces the emissivity is 0.8 or greater, for asphalt shingles a value of 0.91 is acceptable. Part of the observed radiance is a reflection of the cold sky. The radiance temperature of the cold sky was assumed to be -30°C for the clear sky conditions that prevailed at the time of the flight. The reflectivity of the roof surfaces, which is equal to one minus the emissivity, was taken to be 0.09. Under these set of circumstances, the actual roof surface temperatures were 2 to 3°C warmer than the "apparent" temperature slices indicated.

MODEL DEVELOPMENT

A one dimensional model of the roof heat loss was developed to interpret the observed roof temperatures from the flight data. Heat loss through a ceiling and gabled roof system can be simulated by four equations which are expressions of the first law of thermo-dynamics for the roof exterior surface, roof interior surface, attic air, and ceiling. All calculations were made with environmental parameters determined by conditions as they occurred during the time of the aerial flight.

Model calculations were made in three steps:

- 1) Apparent roof temperatures, as determined from the aerial imagery were converted to actual roof temperatures by calculating the effect of roof emissivities.

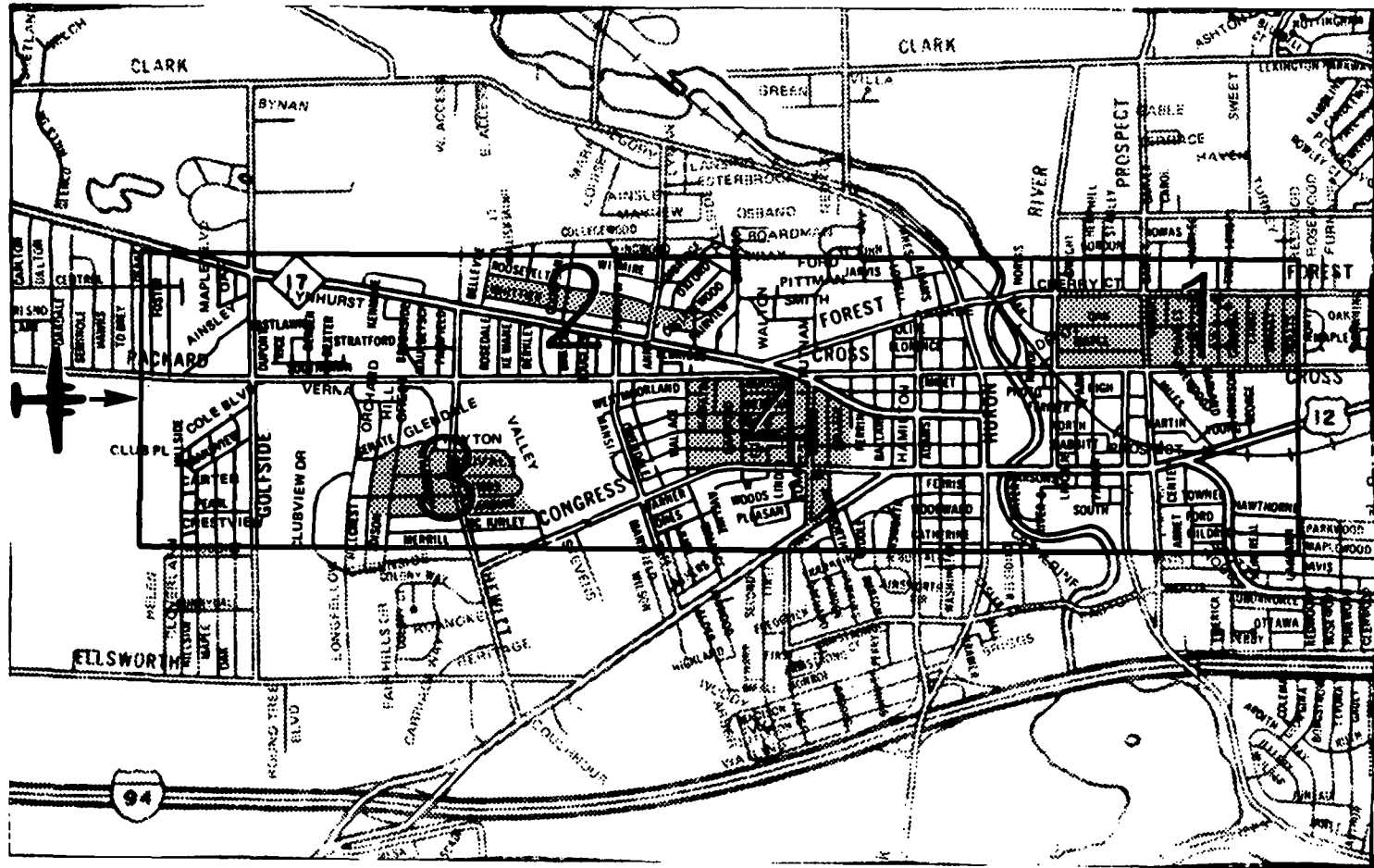


FIGURE 1. CITY OF YPSILANTI WITH OUTLINE OF FLIGHT COVERAGE AND GROUND SURVEYED SUBAREAS

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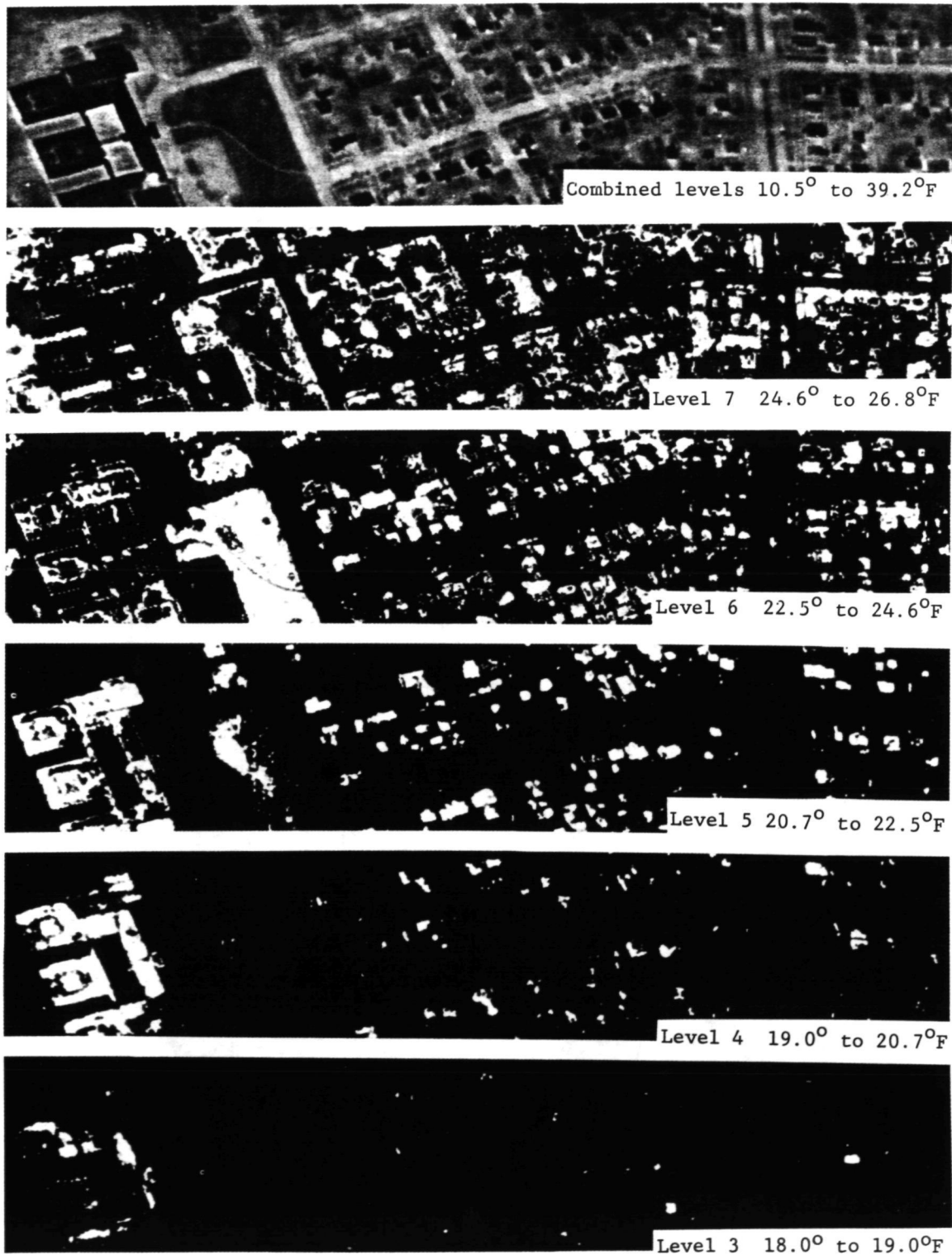


FIGURE 2. CALIBRATED THERMAL IMAGERY
OF YPSILANTI, MICHIGAN. Full range
plus temperature slices. (bandwidth
10.4-12.5 μm) 1004

- 2) Heat loss from a simulated roof was determined as a function of the roof temperature.
- 3) Three equations describing heat balance through the ceiling, the roof, and the attic vents were solved for the ceiling transmission (U) factor (see the diagram in Figure 3).

The equations, for roof heat loss are sensitive to surface emissivities, roof view factors, and the temperatures which determine radiation gains from the physical surroundings and from the ambient air. Radiation energy exchange rates are generally larger than the convective energy exchange in the roof temperature range of interest.

Buildings recorded in the aerial survey which have pitched rather than flat roofs, receive radiation from nearby surrounding surfaces such as adjacent trees and buildings. The total view factor, comprised of areas of sky and surroundings, must add to unity. Thus, the view factor represented by surrounding surfaces is that fraction of the total roof exposure which is occupied by trees, buildings, poles, and other terrestrial features.

The residential flight data included both new and old neighborhoods. Most of the newer homes were oriented with their roof lines parallel to the adjacent streets, and the trees were generally small. Roof pitches tend to be 4/12 to 5/12. On the other hand, many of the older Ypsilanti houses have much greater pitches (8/12 or 10/12) and the roof lines are perpendicular to the street direction. These areas also have larger trees. These older houses are situated on small lots offering greater exposure to one another. For the low pitch roofs, the entire roof is assumed to be exposed to only objects above the horizon. In this case, the view factor (F_{vs}) for the surroundings is calculated to be 0.125. For high pitched roofs (10/12), the eaves of one roof are looking up at the peak of the next house. The peak is receiving radiation from surfaces below the horizon. The maximum angle of incidence for the roof is about 40° at the peak and 60° at the eaves. An average view factor was calculated to be 0.28 for a 10/12 pitched roof.

The value of the heat loss through the roof is used to estimate the temperature T_i just inside the roof by:

$$U_r (T_i - T_r) = \epsilon_r \sigma T_r^4 - \epsilon_r \epsilon_\infty F_\infty \sigma T_\infty^4 - \epsilon_r \epsilon_s F_s \sigma T_s^4 - h_c (T_\infty - T_r) \quad (1)$$

where

U_r is the combined heat transfer conductance of the roof

T_i is inside roof temperature

ϵ_r is roof emissivity

σ is Stefan-Boltzmann constant

ϵ_∞ is ambient air emissivity

F_∞ is ambient air view factor

T_∞ is ambient air temperature

ϵ_s is emissivity of surroundings other than ambient air

F_s is view factor to surroundings

T_s is surrounding temperature

h_c is convective coefficient on the roof surface

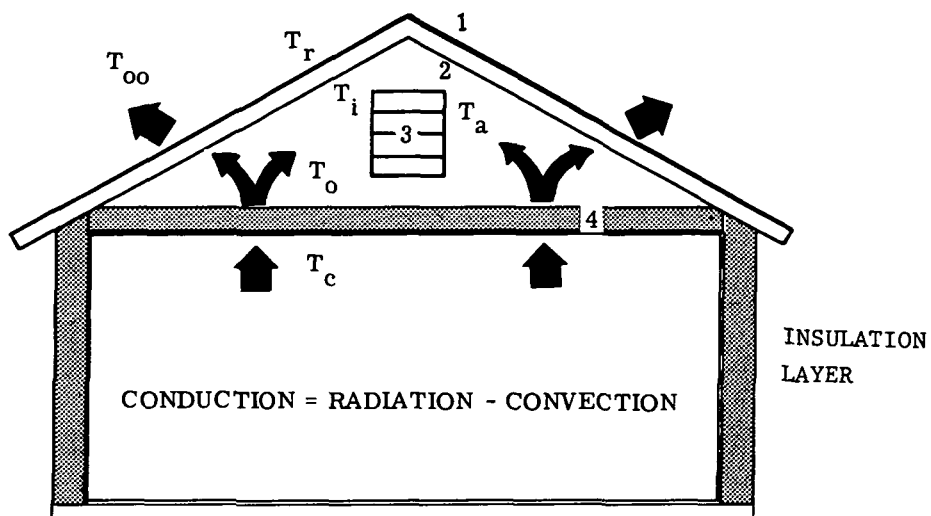


FIGURE 3. DIAGRAM FOR ONE DIMENSIONAL THERMAL MODEL OF HEAT LOSS FOR A GABLED HOUSE.

This equation can be solved directly for T_i , the inside roof temperature assuming T_r is measured by infrared instrumentation.

The transmission coefficient used for the uninsulated roof structure was 0.885. This coefficient represents a roof constructed of a half inch of plywood, a layer of building felt, and a covering of asphalt shingles.

Values of T_i were substituted into the remaining three heat balance equations below and solved for the transmission, U-factor, of the ceiling. Since the equations are non-linear in temperature, the solution is obtained by iteration.

$$U_r (T_i - T_r) = \frac{\sigma T_o^4 - \sigma T_i^4}{\frac{\rho_o}{\epsilon_o} + \frac{\rho_i}{\epsilon_i} \left(\frac{A_i}{A_o} \right) + 1} + h_i (T_a - T_i) \quad (2)$$

where

T_o is attic floor temperature

ρ_o is attic floor reflectivity

ϵ_o is attic floor emissivity

ρ_i is inside roof reflectivity

ϵ_i is inside roof emissivity

$\frac{A_i}{A_o}$ is ratio of inside roof area to attic floor area

h_i is the convective coefficient on the inside of the roof

T_a is attic air temperature

$$h_o (T_o - T_a) = h_i (T_a - T_i) + \frac{A_e}{A_o} U_e (T_a - T_\infty) + q_v \quad (3)$$

where

h_o is heat transfer coefficient on the floor of the attic

$\frac{A_e}{A_o}$ is the ratio of the wall area at the ends of the attic to the attic floor area

U_e is the combined heat transfer conductance of the attic end

q_v is the energy flow out of the vents = $m' Cp (T_a - T_\infty)$

where

m' is mass flow rate based on wind speed and direction or buoyancy force and

C_p is specific heat.

$$U_o (T_c - T_o) = h_o (T_o - T_a) + \frac{\sigma T_o^4 - \sigma T_i^4}{\frac{\rho_o}{\epsilon_o} + \frac{\rho_i}{\epsilon_i} \left(\frac{A_i}{A_o} \right) + 1} \quad (4)$$

where T_c is inside ceiling temperature and U_c is ceiling conductance.

RESULTS

Solutions to the heat balance equations are shown in Figures 4 and 5 as graphs of roof temperature versus the ceiling U-transmission factor and heat loss for the 5/12 and the 10/12 gabled roof construction. The temperatures which correspond to the numbered temperature "slices" produced from the aerial data are also shown on these figures. The model indicates that the upper and lower bounds of the temperatures under the weather conditions for the time of flight should be slice 3 (15°F) and slice 8 (28°F). Nearly all roof temperatures from the aerial thermal imagery lie in this range. The few exceptions may be due to special roofing materials which have unusually low emissive properties. Varying the inside (T_c) and outside (T_o) air temperatures indicate that the above roof temperatures would shift directly with changes in the ambient air temperature, but only slightly with changes in inside temperature.

The model results suggest that knowledge of roof pitch and structure are required to distinguish the amount of ceiling insulation or its equivalent resistance. However, clearly it should be possible to distinguish houses with little or no insulation from those which are well insulated. For this example, temperature level six (23°F) would be the optimum detection boundary for inadequate insulated roof systems.

Questionnaires were sent to approximately one thousand homes located in the four subareas to check the results of the analysis. The questionnaire requested that residences estimate the amount of ceiling insulation in their homes. The responses were compared to the results of the analysis by identifying individual roof temperature.

These survey results which are summarized in Table 1, are positive and relate well to the model studies. While there was too much variation to use the observed roof temperatures to predict precise amounts of insulation, it was possible to interpret thermal aerial imagery for purposes of identifying insulated and non-insulated houses. Using a 5 and 6 level discriminant Figure 6 shows percent correct classification as a function of temperature level.

Gas consumption values were estimated at the time of overflight from data provided by the local utility. Consumption values increase with the poorer insulation conditions but exhibit a large amount of scatter with ceiling insulation undoubtedly due to variability in the house size, interior temperatures, sidewall losses and infiltration losses. Figure 7 shows the distribution of

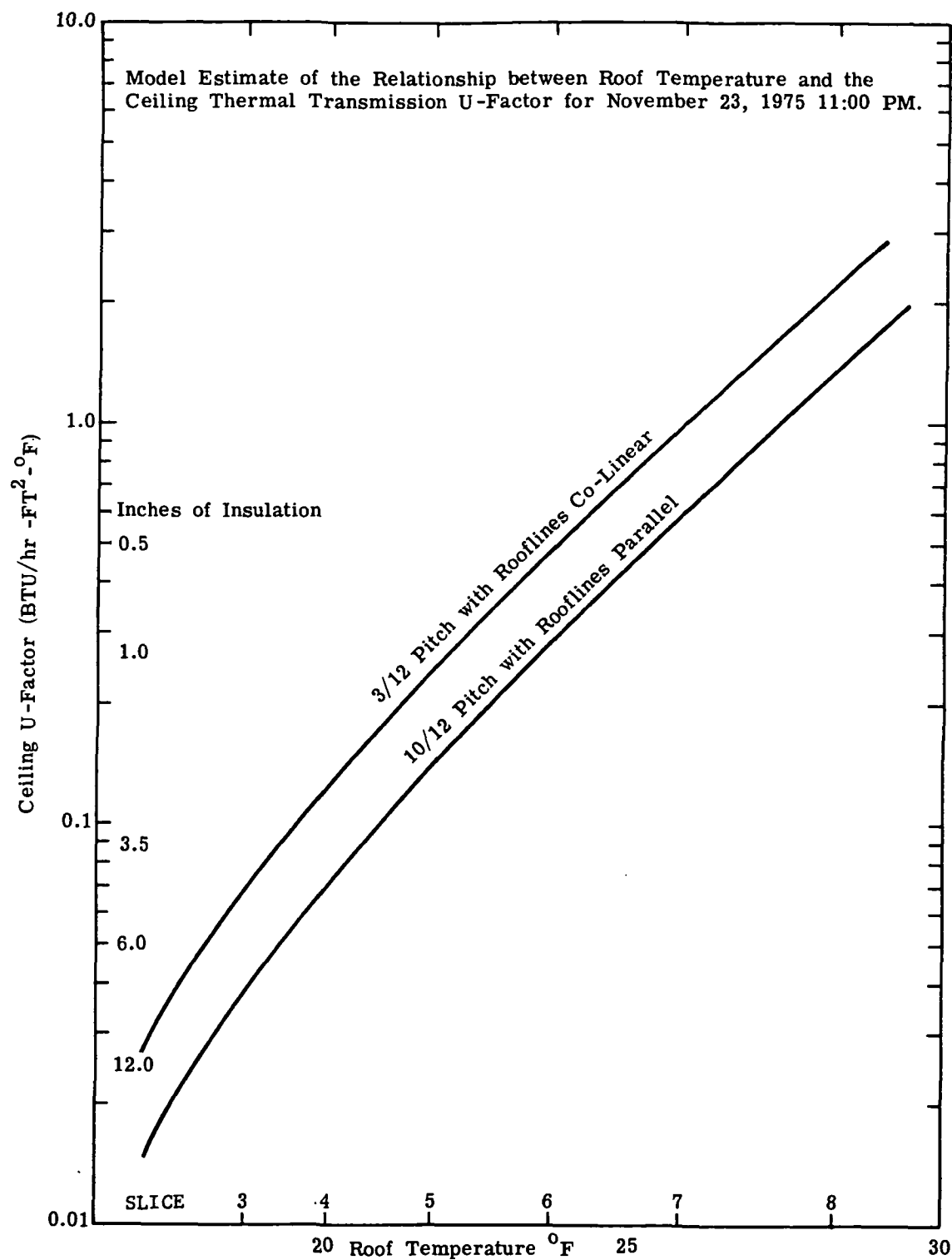


FIGURE 4

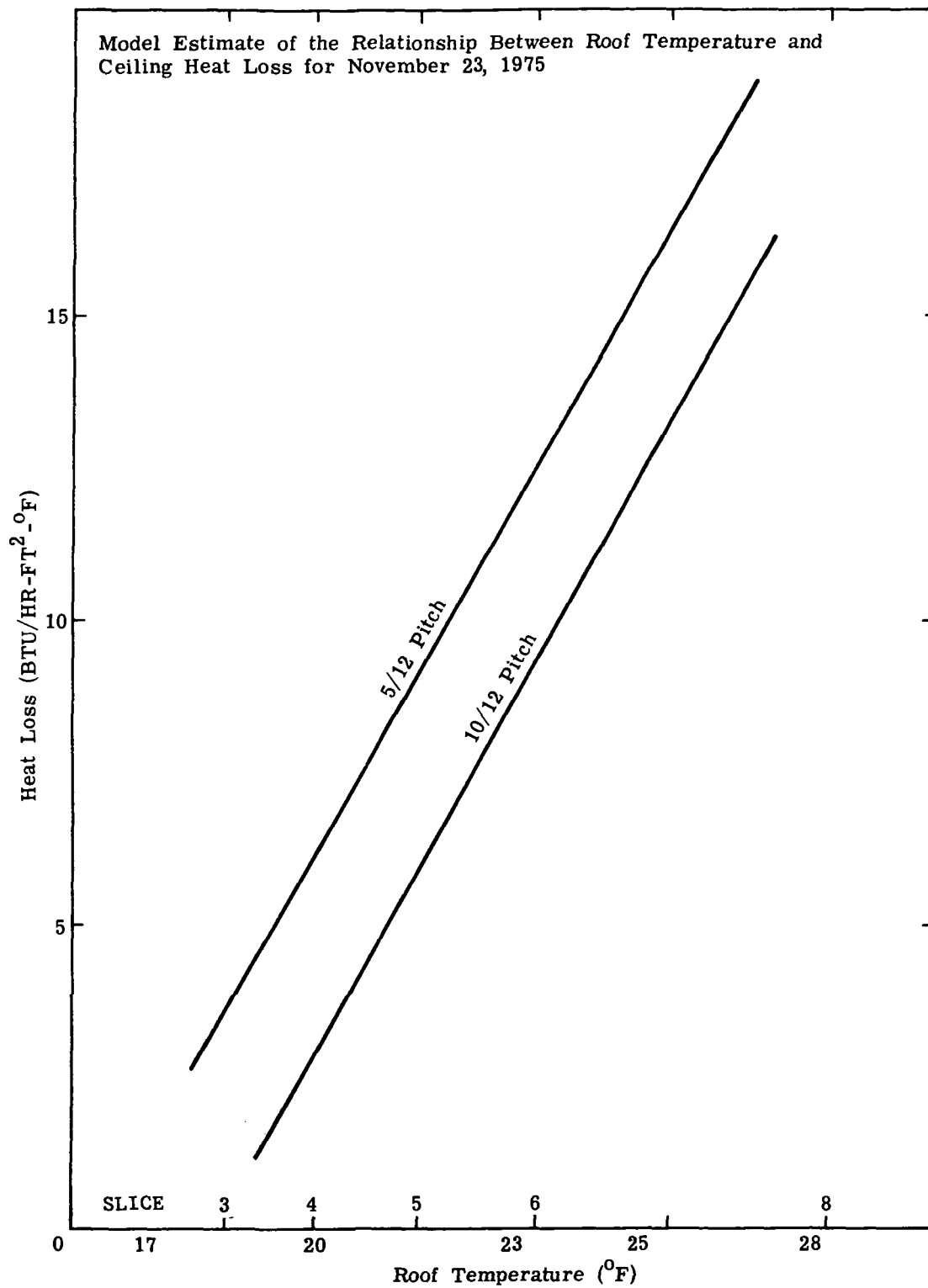


FIGURE 5

TABLE 1. SUMMARY OF SURVEY RESULTS

1011	Temperature Level	Total Responses	Sub-Area 1	Sub-Area 2	Sub-Area 3	Sub-Area 4	Insulated*	Uninsulated	Ave. Report Insulation (in.)	Unknown	Average Gas Consumption KBTU/hr
	3	19	1	13	4	1	14	0	4.9	5	30.4
	4	48	26	18	4	1	39	0	5.25	9	28.5
	5	55	20	6	6	23	43	3	3.0	9	32.0
	6	83	10	0	13	59	43	19	3.3	21	35.4
	7	51	11	0	2	38	16	16	2.4	19	48.4
	Totals	256	68	37	29	122	155	38		63	
	Average Natural Gas Consumption KBTU/hr		26.8	32.5	30.8	41.4					
	Average Reported Insulation (in.)		4.6	5.0	3.9	3.4					

*Insulated Means Two or More Inches of Insulation Reported to be in the Ceiling.

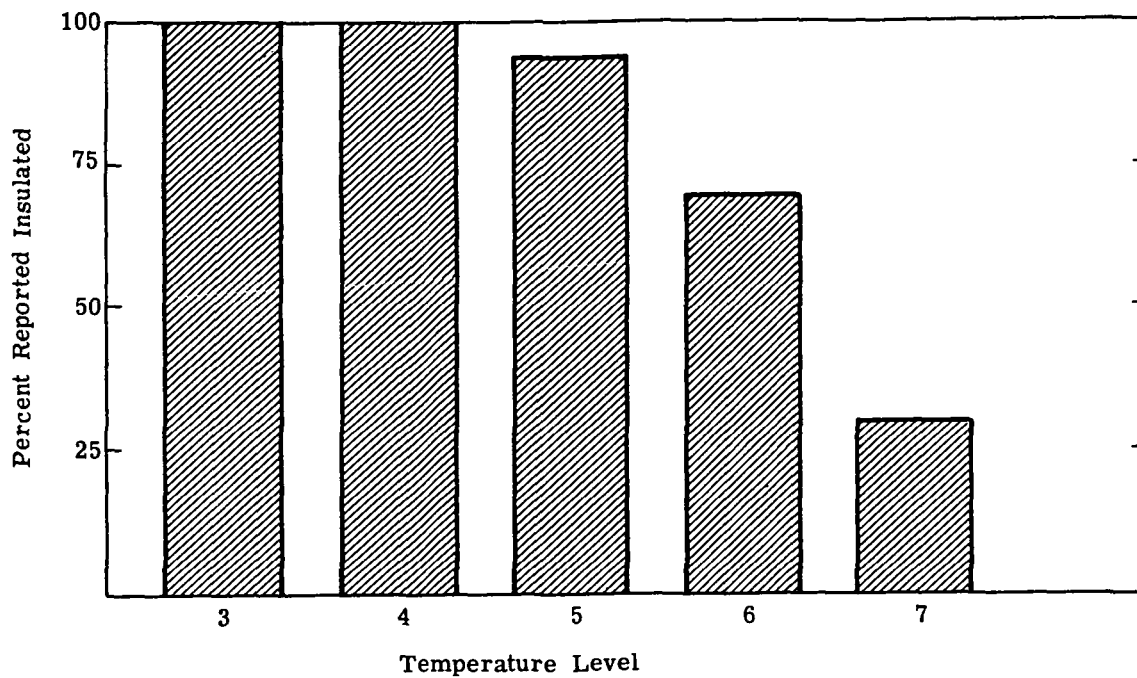


FIGURE 6. PERCENT CORRECT CLASSIFICATION OF REPORTED INSULATED AND UNINSULATED HOUSES USING ROOF TEMPERATURES OBTAINED FROM AERIAL IMAGERY.

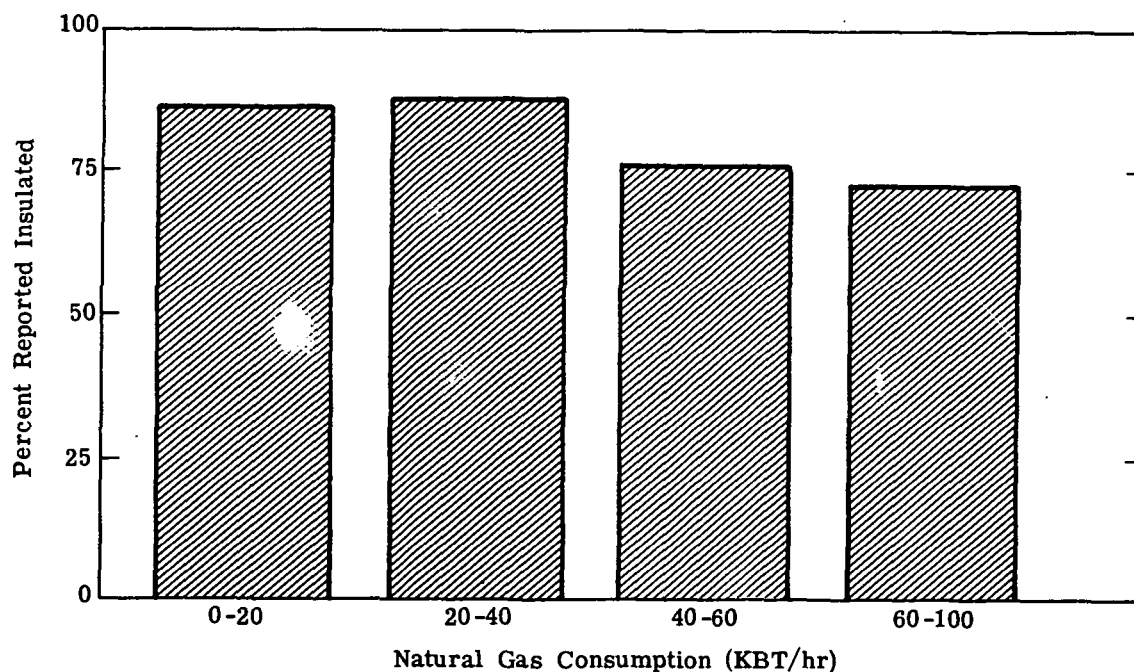


FIGURE 7. GAS CONSUMPTION VALUES WITH REPORTED INSULATION LEVELS.

consumption values to be nearly independent of the amount of insulation. Thus, gas consumption alone appears to offer little capability of discriminating insulated and non-insulated ceilings.

DISCUSSION

As applied to heat loss through building roofs this aerial infrared technique gives promising results but needs further evaluation work. Improvements in prediction capability may improve if finer temperature slices were used and more precise model parameters obtained. However, due to the uncertainty and difficulty in obtaining specific building parameter predictive capabilities of aerial thermography will be limited to a few general classes of insulation level. Causes for the incorrect interpretation include mistakes in the questionnaire response, variation in surroundings and emissivities, and variation in interior temperature and ceiling/roof construction. Further work is needed to more precisely estimate actual insulation thickness and remove the scatter in the results.

The aerial infrared technique can be applied to monitor heat loss of buildings over large metropolitan areas and to support large scale retrofit insulation programs.

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PROCESSING OF SATELLITE IMAGERY
AT THE NATIONAL ENVIRONMENTAL SATELLITE SERVICE

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ABSTRACT

The National Environmental Satellite Service (NESS) image product processing system is a subset of the polar-orbiter satellite and the geostationary satellite systems. These systems enable the day and night monitoring of the environment from markedly different perspectives, thereby fulfilling the needs of an international spectrum of public and private users in the environmental and earth sciences.

This paper is divided into four sections:

1. Overview of the Satellite Data Processing Systems.
2. Image Processing of Polar-Orbiter Satellite Data.
3. Image Processing of Geostationary Satellite Data.
4. Quality Assurance and Product Monitoring.

1. OVERVIEW OF THE SATELLITE DATA PROCESSING SYSTEMS

There are many physical components that are functionally common to both the polar-orbiting and geostationary satellite systems. The earth environmental sensors include the Scanning Radiometer (SR) and the Very High Resolution Radiometer (VHRR) aboard the polar orbiters and the Visible Infrared Spin Scan Radiometer (VISSR) on the geostationary series. Each of these instruments is sensitive to energy in the visible and infrared portions of the electromagnetic spectrum.

Some nonsensor subsystems deal with spacecraft and ground-based command, communications, and power to allow the following functions to be performed:

- (1) spacecraft command and command verification;
- (2) receiving and processing of telemetry (system performance measurements);
- (3) tracking of spacecraft for position/orbit determination and subsequent prediction;
- (4) data flow throughout system;
- (5) spacecraft attitude determination and prediction; and
- (6) data calibration, processing, and display.

All of the above functions and others must be executed properly if image data processing and analysis are to be worthwhile. For example, although a sensor is calibrated and tested extensively prior to launch, the inflight monitoring of its performance is necessary to assure measurement accuracy. Also, knowledge of the precise position and attitude of a spacecraft is vital to the accurate earth location of the data and utility of most image products.

The performance of the above functions is handled by the four major operational elements of the NESS satellite system:

- (1) The Satellite Operations Control Center (SOCC).
- (2) Two Command and Data Acquisition (CDA) Stations in Wallops Island, Virginia, and Gilmore Creek, Alaska.

(3) Ground-based and satellite communications networks.

(4) A quasi-central processing, analysis, and distribution center (the Office of Operations in Suitland, Maryland, and the Central Data Distribution Facility (CDDF) in Camp Springs, Maryland).

The SOCC is responsible for the continuous monitoring, evaluation, and direction of the performance of the spacecraft and data acquisition systems. The CDA stations handle data acquisition, processing, and dissemination using a variety of communications subsystems. The central processing and distribution facilities use a number of computers with manual intervention to ingest, reformat, digitize, earth-locate, display, and quality control the sensor data and subsequent derived products.

2. IMAGE PROCESSING OF POLAR-ORBITER SATELLITE DATA

2.1. SR DATA

Reflected and radiated energy from the Earth is continuously detected in detected in the appropriate wavelengths by the scanning radiometer aboard the polar-orbiting satellites. The SR mirror scans across the spacecraft track from horizon to horizon. The spatial resolution of the ground field decreases away from the subsatellite point, where the visible and infrared channels can resolve 3.2-km and 6.4-km "spots," respectively. The sensor information is recorded on magnetic tape aboard the spacecraft and is played back to the CDA stations when the satellite is within transmission range. The data enter the NESS Suitland facility through hardware/software components, dubbed the Digital Data Handling System, and are demodulated, separated, digitized, and transferred to the NESS large-scale computer (IBM S360/195) for further processing.

Image product processing of SR data includes the creation of:

- polar-stereographic mapped mosaics
- Mercator-mapped mosaics
- time-composites of mapped data
- pass-by-pass gridded images

2.2. MAPPED MOSAICS

The mapping of image data can be broken down as follows.

2.2.1. CALIBRATION

The infrared data are corrected using prelaunch instrument calibration results and continual inflight blackbody versus outer-space temperature comparisons.

Also, a brightness correction is applied to the visible data using a prelaunch-determined relationship between the SR instrument response and solar equivalent brightness.

2.2.2. ENHANCEMENT

The infrared data are also corrected for the attenuation of the signal passing through the Earth's atmosphere. Water vapor is considered the major attenuating constituent.

A correction is made to the visible data for differences in solar illumination of the Earth scene due to varying sun angle.

2.2.3. EARTH LOCATION

The mapping process continues with the earth location of a subset of data points or "benchmarks," using such information as predicted satellite orbital position, attitude, time, and a knowledge of sensor geometry. The benchmark latitude and longitude inputs are transformed into coordinates in the desired map projection array. Since the mapping is done on a pass-by-pass basis, the

limits of this array must also be computed. The mapping resolution is substantially poorer than that of the raw data, creating a surplus of samples for each mapped location.

2.2.4. MAPPING PROCEDURE

Using the calibrated, enhanced data and the benchmark data array and array limits as input, the mapped position coordinates for each sample are computed by a linear interpolation. Redundant plotting of samples into the mapped sector of desired resolution is done until the input data are depleted. The mapped sector is then transferred to disk storage, awaiting further product processing.

Three mapped data bases exist for both the polar-stereographic and Mercator projections:

- visible
- nighttime infrared
- daytime infrared

Each of the polar-stereographic mapped arrays is aligned with the National Meteorological Center's (NMC) Numerical Weather Prediction grid for ease in meteorological application of the satellite imagery. The mapped resolution varies from approximately 15 kilometers at the equator to 30 km at the poles.

The Mercator-mapped arrays are aligned parallel to the equator, covering a latitude belt from 40°N to 40°S along the full Earth longitudinal span. The resolution is approximately 10 km at the equator with an improvement poleward.

2.3. PASS-BY-PASS GRIDDING

Due to the computer resource cost and unsuitability for some user applications of mapped data, NESS also produces pass-by-pass gridded imagery. While mapping entails the fitting of the data to conform to a mapped projection, gridding involves the placement of grids into the data stream in the proper geographical locations (or more precisely, at the proper time). The grids consist of latitude/longitude lines and geographical/political boundaries. The earth location (or data stream positioning) of the grids is accomplished once a day for the following 14 orbits of the spacecraft using predicted satellite orbit and attitude, time, and geometry. A grid feature file consisting of geographical/political latitudes and longitudes is used as input to this grid table production.

A table of grid positions, within the data stream, for each orbit of the day is produced.

The melding of grids and data is performed during the creation of each gridded, orbital display product.

2.4. MAPPED TIME COMPOSITES

NESS produces limited area, multiday brightness, and temperature composites of polar-mapped data for specific user application. Areal coverage of ice and snow can be deduced from mapped data by saving only the minimum brightness or maximum temperature value for each mapped point over a multiday--in this case, 10-day--period. This process effectively removes the transient cloud cover, exposing the surface background features for snow/ice extent analyses. The composites are produced daily over the north and south polar regions for the previous 10-day period.

2.5. MAPPED DISPLAYS

The NESS produces a variety of displays of the mapped data bases for user application. These range from photo reproductions of full-hemisphere mosaics to facsimile displays of specific earth sectors. The displays are produced in various map scales, sizes, and areal coverage in response to user needs.

This imaging process begins in the IBM S360/195 with software which processes the data for the Digital Muirhead Display (DMD) devices that produce 25-cm by 25-cm negatives. Photo processing and reproduction are done in the Visual Products Support Branch.

The facsimile display media include the standard weather facsimile networks (FOFAX, NAFAX) using such devices as Alden Electrolytic paper recorders and weather facsimile images rebroadcasted via geostationary satellites (WEFAX) and recorded by users on either photofacsimile or other facsimile recorders.

2.6. VHRR DATA

Both the visible and infrared channels of the VHRR resolve an 0.8-km spot at the subsatellite point. Because of the higher data resolution, only about eight minutes of VHRR data per orbit can be recorded on the satellite. The data can then be transmitted to either of the CDA stations or a readout station located in San Francisco, California. The VHRR system also includes a direct readout capability, the High Resolution Picture Transmission (HRPT) subsystem. Users with proper ground equipment can receive the data as the spacecraft passes within transmission range.

The processing of VHRR data at the NESS (by the Environmental Products Group) consists of a large amount of manual intervention. Hardcopy photographs are received from the ingest facility and are analyzed to generate a number of products with generally hydrological application. These include a Gulf Stream Analysis, Great Lakes Ice Chart, Great Lakes Surface Temperature Chart (in the summertime), Alaskan and Labrador Ice Analyses, and the U.S. Snow Basin Mapping. These products are disseminated by mail, facsimile, teletype, and telecopier.

3. IMAGE PROCESSING OF GEOSTATIONARY SATELLITE DATA

The Geostationary Operational Environmental Satellites (GOES) possess equatorial, earth-synchronous orbits, which allow them effectively to hover over the same earth location continuously. The respective scenes viewed by the VISSR, then, aboard the Eastern Satellite with a subsatellite longitude of 75°W and the Western Satellite, located above 135°W, change very little from picture to picture. The VISSR mirror sweeps from earth horizon to horizon viewing an 8-km swath during each sweep. The mirror is stepped down so that adjacent swaths are viewed during successive sweeps.

The visible and infrared data are transmitted to the Wallops CDA station and are demodulated, synchronized, preprocessed, and retransmitted to Suitland. Much of the preprocessing takes place in the Synchronizer/Data Buffer (S/DB) computer. The visible data, with a raw 1-km resolution, are adjusted for sensor bias and can be reformatted into resolutions of 1, 2, or 8 km. The infrared data may be output in either 8-km or 8x4-km resolutions. These data are sent to Suitland either by retransmission via the Eastern Satellite or landline communications.

The S/DB computer hosts another important event in the GOES imaging system. Earth-located gridding information is produced at Suitland in essentially the same fashion as polar-orbiting satellite grid positions are predicted. In this case, the picture coordinate locations of the political/geographical boundaries and latitude/longitude lines are produced for each picture, instead of on an orbital basis. Inputs to the gridding algorithm include predicted satellite position (orbit), attitude, time, and sensor geometry. The gridding data are transmitted to Wallops via a computer-to-computer link and telephone line named the Grid Transfer System. The S/DB receives and properly inserts the grids into the real-time VISSR data stream for each GOES frame.

The VISSR Ingest Computers (VIC) at Suitland create a data tape that interfaces with the photofacsimile display devices. The data, then, may be saved for later processing and/or displayed in near real time. The NESS Suitland facilities handle only a portion of the display and distribution of GOES imagery. The retransmitted signal from the spacecraft is also relayed via line-of-sight microwave communications to the CDDF in Camp Springs. From there, pertinent data may be routed to any of the five Satellite Field Service Stations (SFSS)

located in Washington, D.C., Miami, Kansas City, San Francisco, and Honolulu. Each of the SFSS's serves as a focal point for analysis and distribution of satellite imagery to regional environmental centers.

The VISSR data are available to users in full-disk displays in resolutions of 4-km visible and 4x8 kilometers or 8-km infrared. Sectors of visible data, covering a subset of the full-disk area, in 1- and 2-km resolution can also be formatted at ingest time.

3.1. MOVIE LOOPS

Animated sequences of successive VISSR picture frames called "movie loops" are created daily at NESS using visible and infrared data of different resolutions over varying geographical locations. The process, using an Oxberry 16-mm recorder (a camera system which is designed to produce motion pictures from still-scene sequences), is controlled by a minicomputer.

3.2. ADDITIONAL GRIDDING

The "automatic" gridding system described above is used to provide grids to all GOES images except for 8-km infrared and movie loops. These products use computer-produced overlay grids, hand-fitted over images, which are then photographed. The overlay grids are created using earth-location software, predicted satellite orbit and attitude, time and a master feature file, in a manner similar to the polar-orbiter satellite grid generation process.

In this case, the IBM S360/195 has been used to create data tapes that produce the clear film grid overlays, using the DMD's and photographic processing.

3.3. MAPPING

Some operational mapping of GOES images is performed, but it is done on a limited basis. At this time, two Eastern Satellite pictures are mapped daily--one visible and one infrared, both in Mercator projections. The mapping process is essentially the same as that for the polar-orbiting satellites, involving calibration, earth location of benchmark arrays, interpolation through these arrays, and storage of the mapped information in an area on the S360/195 disk.

Mapped imagery is output in facsimile form for transmission via standard weather facsimile circuits.

3.4. MANUALLY DERIVED ANALYSES

The Synoptic Analysis Section uses multiformatted VISSR, SR, and VHRR imagery to prepare a number of daily, useful meteorological analyses for aid to the analysis and forecast missions of the NWS. Among these are (1) nephanalyses delineating cloud cover and type, (2) windflow and moisture analyses as input to NMC numerical analysis and prediction models, and (3) tropical storm warnings and classifications.

4. QUALITY ASSURANCE AND PRODUCT MONITORING

The quality control function is a necessary part of any system that expects to deliver products in an accurate, timely, and consistent fashion. The NESS Operational Products Monitoring Section (OPMS) performs the monitoring and evaluation of the ingest, processing, and dissemination of data and derived products from the NESS operational satellite systems.

The monitoring by OPMS personnel includes around-the-clock identification and evaluation of real and potential problem areas in the entire NESS product processing system. Such occurrences as the failure of an operational computer program to successfully complete or a breakdown in the facsimile transmission of imagery must be diagnosed. A course of action is then taken which may involve a number of NESS processing components. Many problems are handled immediately while others may require extensive post facto analysis.

Review and discussion of problem areas with pertinent personnel is aided by a weekly briefing conducted by OPMS.

The first year of this quality assurance effort marked an improvement from 75 to 90 percent in the successful output of products from the NESS operational imagery system, despite a large-scale increase in both the number of products and the complexity of the overall facility.

5. CONCLUDING REMARKS

For the sake of brevity, this paper has avoided detailed description of specific image display products. The NESS operational facsimile transmission schedule alone consists of approximately 30 mapped products covering a range of geographical locations, map scales, and data types. To help inform users or potential users of satellite imagery, the National Oceanic and Atmospheric Administration (NOAA) has published a "Catalog of Operational Satellite Products," edited by Hoppe and Ruiz (1974) and will soon publish an updated version, "NOAA Catalog of Products, Chapter III" (Dismachek, 1977). Each of these publications deals with satellite image products and other satellite-derived products, such as alphanumeric messages and digital magnetic tapes, in greater detail than does this paper.

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REMOTE SENSING OF OCEAN COLOR AND
DETECTION OF CHLOROPHYLL CONTENT

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ABSTRACT

The chlorophyll enrichment of the water in an equatorial upwelling was surveyed and described during two one month periods in 1975 and 1976 with the aid of a radiometer specially designed for the airborne measurement of ocean color. Based upon the results of this experiment and some theoretical considerations, a relation is proposed between airborne measurement of difference of albedos at two wavelengths in the blue and green, and the concentration of chlorophyll in the ocean.

1. INTRODUCTION

It has for many years been known that ocean color, or more exactly the radiation backscattered by seawater in the visible spectrum, is linked to chlorophyll pigment content, and that this can be employed in the remote sensing of chlorophyll concentration. YENTSCH (1960) measured the absorption coefficients of chlorophyll-a extracted from marine plants and showed that the presence of chlorophyll deplaces the sea water transparency maximum from blue towards green. He suggested that the color of the ocean is closely related to the chlorophyll content. CLARKE, EWING and LORENZEN (1970) performed experiments using this remote sensing method by making airborne measurements of the light spectra backscattered by the ocean. Numerous airborne experiments have since been made, all of which have been based upon a measurement in the blue at the chlorophyll absorption maximum (BAILEY and WHITE (1970), HOVIS, FORMAN and BLAINE (1973), AVERSEN, MILLARD and WEAVER (1973), PEARCY and KEENE (1974). Although easy in the principle, this remote sensing method poses several problems of a practical nature, and in the interpretation of results which are perturbed by other parameters inherent to radiative transfer in the atmosphere-ocean system and to the optical properties of sea water.

The results here presented are founded upon the above principle, but the method employs the calculation of differences between albedos measured at several wavelengths. This permits the measurement of ocean color, and thus determination of chlorophyll content independent of measurement conditions and, moreover, independent of the cloud cover under which the aircraft flew. This result is of particular interest for potential applications in equatorial regions where nebulosity is considerable and very variable. It was in this manner that the chlorophyll enrichment of waters from an equatorial upwelling could daily be observed and described during two one month periods in 1975 and 1976 on a quasi operational basis.

2. MATERIAL AND METHODS

The method is based upon the measurement of the spectral albedo of the sea with a four channel radiometer which simultaneously measures radiation upwelling from the sea and the downwelling radiation. The radiometer is equipped with interference filters having a narrow bandwidth ($\Delta\lambda \approx 10$ nm) and measures the up-

welling irradiance E_u or radiance I_u , and the downwelling irradiance E_d at 466, 525, 550, 600 nm. The I_u measurement is made with a polarizer at an incidence of 45° , near the Brewster angle in order to minimize surface reflection. The ratio of the two measurements (E_u/E_d or $\pi I_u/E_d$) furnishes an albedo value for the ocean; the relative calibration of the upward and downward sensors is made by aiming them at a single diffuse surface. The reproducibility of the albedo measurements thus obtained was evaluated as $5 \cdot 10^{-4}$. This radiometer and an infrared radiometer measuring sea surface temperature, were borne by an aircraft flying at low altitude in order to minimize the influence of atmospheric scattering.

The exploitation of measurements made in the study area on the equator was particularly problematical due to the fact that in this region the nebulosity is extremely variable, and the sky is rarely perfectly clear. Under these conditions, the upwelling radiation is primarily a function of the incident irradiance. This is illustrated by Fig.1-a, in which is presented a recording of downwelling irradiance, E_d , and of upwelling radiance, I_u , at 466 nm, which was made during the flight of July 13, 1975. As the cloud cover in this case varied from 10 % to 50 %, the I_u variations are essentially due to changes in E_d . In order to obtain a measurement independent of E_d variations, albedo A is calculated :

$$A = \frac{\pi I_u}{E_d}$$

Albedo thus calculated contains both the term due to backscattering from the sea water, which is affected by the presence of chlorophyll and which has thus to be measured, and the term associated with the sea surface reflection of downwelling radiation, which is a source of error. The nature of this reflection changes when one passes from a clear sky to a cloudy sky, where downwelling radiation becomes more diffuse. The method sometimes suggested (e.g., by HOVIS, FORMAN and BLAINE, 1973) which consists of taking the ratio between upwelling radiances at two wavelengths is not applicable in this case because the measured values include an excessive term of error which is due to reflection in the presence of clouds.

A method using difference between albedos was developed in order to obtain a measurement which is as independent as possible of this reflection. This albedo difference method permits the elimination of most sources of error, such as surface reflection, which is independent of wavelength in the spectral bandwidth considered, and the effects of whitecaps and light scattering due to aerosols, which vary slowly in function of wavelength. In Fig. 1-b, the radiance ratio method is compared with the albedo difference method at 466 and 525 nm. Although the general allure is similar, with a minimum at point B (near 10h00), it is noted that the radiance ratio is much more noisy, particularly in the period between 9h40 and 9h50 during which the cloud cover and downwelling radiation E_d (Fig.1.a) were highly variable. The measurement of I_u with a polarizer greatly diminishes the effect of reflection. Reflection on the sea surface is somewhat diffuse due to the sea state however, and part of this radiation still comes from reflection. This effect is particularly evident for the diffuse radiation corresponding to an overcast sky. It thus can be concluded that the albedo difference method is much less affected by measurement conditions than is the radiance ratio method.

In Fig.1.c, are found the albedo differences $A_{466} - A_{525}$ and $A_{550} - A_{600}$, and sea surface temperature (Fig.1.d) recorded for the same period as referred to in the preceeding paragraph. The elimination of variations in downwelling radiation allows albedo difference variations associated uniquely with the internal optical properties of the ocean to appear. The "blue-green" $A_{466} - A_{525}$ difference diminishes when the thermal front is traversed, and is nul at the minimum temperature near point B, indicating that the colder waters are green and chlorophyll rich. The $A_{550} - A_{600}$ difference increases at the same time, indicating greater turbidity which is associated with chlorophyll. Variations in these albedo differences are associated with variations in the optical properties of sea water.

3. MEASUREMENT INTERPRETATION

A theoretical model was constructed in order to correlate albedo differences to contents in absorbing matter (chlorophyll-a) and scattering matter (sediments). The model was verified by comparison with several samples taken in-situ by boat.

3.1 - The theoretical model.

The medium of the model is assumed homogeneous, and optical properties adopted for the constituents of this medium are the results of previous measurements. Optical properties are defined by

a , the absorption coefficient (m^{-1}),
 b , the scattering coefficient (m^{-1}),
 $p(\theta)$, the scattering phase function which represents the light fraction deviated at the angle θ .

The principal terms contributing to coefficients a and b are described in tables 1 and 2, and it is possible to write

$$a = a_o + n_{chl} \cdot a_{chl} + a_y \quad (1)$$

where a_o is absorption by pure water,
 n_{chl} , chlorophyll concentration (mg/m^3)
 a_{chl} , absorption by chlorophyll (for $1 mg/m^3$),
 a_y , additional absorption by yellow substance if present,

and :

$$b = b_o + b_p \quad (2)$$

where b_o is scattering by pure water,
 b_p , scattering by particulate matter.

The numerical values of b_o , a_o and a_{chl} which are needed in the model are found in table 3. The coefficients b_p and a_y are defined by their values at 500 nm, and are λ^{-1} and $\exp(-k\lambda)$ dependent

$$b_p(\lambda) = b_p(500) \frac{500}{\lambda} \quad (3)$$

$$a_y(\lambda) = a_y(500) \exp\{0,014(500-\lambda)\} \quad (4)$$

with λ is nm. The phase function can be developed as follows

$$p(\theta) = \frac{b_o p_o(\theta) + b_p p_p(\theta)}{b_o + b_p} \quad (5)$$

where $p_o(\theta)$ is relative to molecular scattering, and $p_p(\theta)$ is relative to particle scattering. In that which follows, phase functions $p_o(\theta)$ and $p_p(\theta)$ are from MOREL (1973), and their respective weights are varied by way of b_p . All of the above data are introduced into the theoretical model.

The theoretical computation of backscattered albedo necessitated the solution of the radiative transfer equation for an absorbing and scattering medium. Several computation methods can be used, and have been compared by DEVAUX, FOUQUART, HERMAN and LENOBLE (1973). Examples of the application of the theoretical computations to the ocean have been given by KATTAWAR and HUMPHREYS (1976), GORDON and BROWN (1973), and PRIEUR (1976). Computations based upon the successive scattering order method are developed in this paper.

In this computation, an expansion of the radiance in a Fourier series in azimuth is obtained by representing phase function as an expansion in Legendre polynomials. Computation time is reduced by the use of the so-called "trun-

cation of the forward peak" approximation, which permits the reduction of terms entering into the development of the phase function to 28. The accuracy obtained by this method should be excellent (2 %), but the results for backscattered albedo, A, can be expressed by the following simplified formula whose lower 10 % precision is acceptable due to a similar imprecision in the absorption and scattering data

$$A = m \frac{b_o}{a} + n \frac{b_p}{a} \quad (6)$$

where constants m and n are determined from the computations as

$$m = 7.55 \cdot 10^{-2}$$

$$n = 0.23 \cdot 10^{-2}$$

Computations demonstrate that A is only weakly influenced by the geometrical repartition of the incident radiation. This equation permits the direct relation of measurement of A to the internal optical properties of the ocean.

By introducing Eq. 1,2,3 and 4 into Eq.6, the influence of each factor can easily be evaluated at any wavelength. It again is found that chlorophyll is the main cause of albedo variation near 450 nm, while the turbidity characterized by b_p has a maximal influence near 550 nm. All of the parameters considered, however, including the absorption by yellow substance a_y , have an influence upon the measurements at different wavelengths, and a method permitting the separate evaluation of each of each parameters is called for.

3.2. - Measurement of the turbidity coefficient b_p .

Between 525 and 650 nm, outside of the chlorophyll absorption band, the albedo is primarily sensitive to the coefficient b_p . This is shown in figure 2, where the albedo difference $A_{550} - A_{600}$ is plotted as a function of $b_p(500)$ with the aid of Eq.1,2,3,4 and the data found in table 3. The measurement of $A_{550} - A_{600}$ thus constitutes a method of b_p determination, but it must be noted that the presence of yellow substance (or an other absorber) can modify the anticipated results.

Experimentally, an increase of $A_{550} - A_{600}$ was regularly observed while flying over zones rich in phytoplankton. A slight increase of $A_{550} - A_{600}$ thus is observed in Fig.1.c at 9H55. Although variations of $A_{550} - A_{600}$ are often, as in this case, at the limit of experimental sensitivity, it nevertheless was possible to map this difference. Maps of the two albedo differences, $A_{550} - A_{600}$ and $A_{466} - A_{525}$, have the same general features, demonstrating the close relationship between turbidity and chlorophyll content.

3.3. - Determination of chlorophyll content.

Knowing b_p , it is possible to evaluate the correction which should be applied to the chlorophyll content deduced from measurements in the blue region. It was demonstrated how the measurement of two differences ($A_{466} - A_{525}$ and $A_{550} - A_{600}$), permits an independent determination of b_p and n_{chl} (chlorophyll concentration) (VIOLLIER, DESCHAMPS and LECOMTE, 1977). As it is evident that these two coefficients are dependent, however, it is probably possible to directly deduce chlorophyll concentration uniquely from the $A_{466} - A_{525}$ difference. This more practical method was used in this paper, but is presupposes that a mean relationship between b_p and n_{chl} be known for the study area.

The relationship between b_p and n_{chl} is not well known, and probably depends upon the type of phytoplankton encountered. Lacking better knowledge of this subject, the following relation is assumed

$$b_p = 0.05 + 0.5 \cdot n_{chl} \quad (7)$$

(b_p in m^{-1} , n_{chl} in mg/m^3)

The values of the coefficients are based upon the observed extreme values of b_p and n_{chl} in the study area :

$$b_p \text{ from } 0.05 \text{ to } 0.6 \text{ m}^{-1}, \quad n_{chl} \text{ from } 0 \text{ to } 1 \text{ mg/m}^3.$$

This relation may be associated with Eq.1,2,3,4 and 6. The two curves found in Fig.3, which in one case corresponds to the absence of yellow substance, and in the other to a high yellow substance content, give the obtained relation between the albedo difference $A_{466} - A_{525}$ and chlorophyll content n_{chl} .

In Fig.3, there is also presented an experimental relation (curve 3) established upon the basis of four in-situ measurements made by R.V. CAPRICORNE. Chlorophyll content measurements made between 0 and 20 meters are found in table 4. Chlorophyll content values which vary with depth can not be directly compared with the theoretical values of a homogeneous model. In order to make the comparison, the content value at a given depth was therefore weighted by a coefficient equal to the transmission of light to twice that depth. The results of this weighting were placed in Fig.3 as a function of simultaneous airborne measurement of $A_{466} - A_{525}$. It is noted that the experimental curve (3) is in fairly good agreement with that inferred from the theoretical model, although the theoretical curve (1) clearly overestimates the chlorophyll concentration. This difference could derive from one of the numerous approximations introduced into the theoretical model (that furnished by Eq.7, for example) or due to yellow substance. This result demonstrates that the improvement of this method would require the taking of a few sea truth measurements during the aerial survey, in order to adjust the relationship between albedo difference and chlorophyll content.

4. RESULTS OF THE AIRBORNE MEASUREMENT SURVEYS.

Two airborne remote sensing surveys of chlorophyll content, totaling more than thirty flights, were made during June-July of 1975 and 1976 off shore Gabon (Central West Africa) in the Gulf of Guinea. The study area is situated on the equator, between Sao Tomé Island and Cape Lopez. During the June-July study period, the hydrological conditions favor the development of coastal upwellings (DUFOUR and STRETTA, 1973 ; VOITURIEZ, VERSTRAETE and LE BORGNE, 1973 ; HISARD and MARLIERE, 1973).

The cold upwelled water ($< 23^{\circ}\text{C}$) from the south encounters the warm water ($> 25^{\circ}$) of the Guinea Current coming down from the north, and this provokes a fairly clearcut thermal front with a surface temperature difference on the order of 2°C within several nautical miles. The movements of this front can easily be watched by airborne sensing methods (STRETTA, NOEL, and VERCESI, 1975). When the upwelling starts, the cold water invades the whole sector, starting from Cape Lopez and propagating to the north. The warm water returns a few days later by moving towards the south. Several cycles of north-south oscillations of the surface thermal front are observed, and the study area between Cape Lopez and Sao Tomé Island accordingly passes through a series of warm and cold phases.

After each flight, the measurements are used in the drawing of maps of surface temperature and albedo difference. The daily flight plan is formulated as a function of previous maps so as to cross the thermal front several times.

The appearing of cold waters rich in mineral salts is translated as phytoplankton development and a greener ocean color. This corresponds to the extreme $A_{466} - A_{525}$ measurement values which pass from 120.10^{-4} for warm, chlorophyll poor water (less than 0.3 mg/m^3), to -30.10^{-4} for cold, chlorophyll rich water (about 1 mg/m^3). Coastal waters are much richer, particularly near the estuaries of the Ogoüé and Gabon rivers.

In Fig. 4a,b,c, are found three of the maps obtained in 1975 for three typical flights :

- July 6, 1975, corresponds to the maximal northerly development of a cold phase with a well defined thermal front forming an arc between Cape Lopez and Sao Tomé Island.
- July 11, 1975, corresponds to a warm phase subsequent to invasion of the whole area.
- July 13, 1975, at the beginning of a new cold phase.

The temperature and chlorophyll content deduced from $A_{466}-A_{525}$ (from curve (1) in Fig.3) at the point most frequently flown over ($0^{\circ}30'S$, $8^{\circ}E$), were selected in order to describe the succession of warm and cold phases. This point is situated 40 nautical miles from the coast, and is only very slightly influenced by the Ogoué river effluent.

In 1975 (Fig.5.a) there thus are successively observed :

- a warm phase until July 2,
- cold phase from July 3 to 8,
- a warm phase from July 9 to 12,
- a cold phase starting July 13.

In 1976 (Fig.5.b), the most pronounced phases are :

- warm phases from June 20 to 26, and from July 6 to 11,
- cold phases from June 27 to July 4, and starting July 12.

The chronology of the observations thus shows a good local correlation between chlorophyll content and sea surface temperature at the point considered. Maximal concentrations are obtained during cold phases and attain 1 mg/m^3 . The evolution of chlorophyll content seems to be about one day late with respect to changes in surface temperature, which may be interpreted as the time needed for phytoplankton growth. In 1976, cold phase temperatures were lower and chlorophyll concentrations were higher than in 1975.

5. CONCLUSION.

The albedo difference method developed for the remote sensing of ocean color and the measurement of chlorophyll content has shown itself to be particularly useful in the making of airborne measurements under cloudy skies, which permits the technique to enter into operational service. Although chlorophyll content values measured with method generally run parallel to the in situ values, they must be used with precaution due to the incertitude existing in the relationship between the optical properties of sea water and the chlorophyll content. Results obtained from two airborne survey campaigns observing an equatorial upwelling off the Gabon coast demonstrate the potential use of this remote sensing technique in the spatial and temporal study of the phenomenon.

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TABLE 1. - ABSORPTION CHARACTERISTICS

	Substances absorbing light	λ -dependence (wavelength = λ)	References
a_o	sea water	window of maximum transmission at 450 nm	Clarkes et James (1939) Prieur (1976)
a_y	dissolved material (yellow substance)	increase towards short λ $a_y(\lambda) = a_y(\lambda_1)e^{0,014(\lambda_1 - \lambda)}$ (λ in nm)	Jerlov (1968) Prieur (1976)
a_{chl}	chlorophyll a (pigment in particulate matter)	absorption band around 440 nm and 675 nm	Yentsch (1960)
a_p	other absorbed in particulate matter	variable, assumed nul in this study.	

TABLE 2. - SCATTERING CHARACTERISTICS.

	Substances absorbing light	λ -dependance (wavelength = λ)	References
b_o	sea water	$\lambda^{-4,3}$	Morel (1973)
b_p	particulate matter	λ^{-1} (law assumed for the purposes of this study)	

TABLE 3. - NUMERICAL VALUES OF OPTICAL COEFFICIENTS INTRODUCED IN THE THEORETICAL MODEL.

λ (nm)	466	525	550	600	References
b_o (m^{-1})	0,0039	0,0023	0,0019	0,0014	Morel (1973)
a_o (m^{-1})	0,0155	0,050	0,068	0,245	Prieur (1976)
a_{chl} (m^{-1})	0,065	0,01	0,006	0,007	Yentsch (1960)

TABLE 4. - IN SITU MEASUREMENTS MADE BY R/V CAPRICORNE.

Date	location	Chlorophyll content (mg/m ³)					Aerial Measurement of A ₄₆₆ - A ₅₂₅	
		depth	0 m	5 m	10 m	15 m		20 m
20.6.76	1°S 7°30 E		0,20	0,19	0,19	0,48	1,41	38.10 ⁻⁴
21.6.76	0° 8° E		0,18	0,18	0,25	0,15	2,15	57.10 ⁻⁴
22.6.76	1°S 7°30 E		0,11	0,07	0,11	0,58	0,87	74.10 ⁻⁴
13.7.76	1°S 8°23 E		0,55	0,73	0,64	0,31	0,33	21.10 ⁻⁴

(the time intervals between the "in situ" and aerial measurements are of less than 4 hours).

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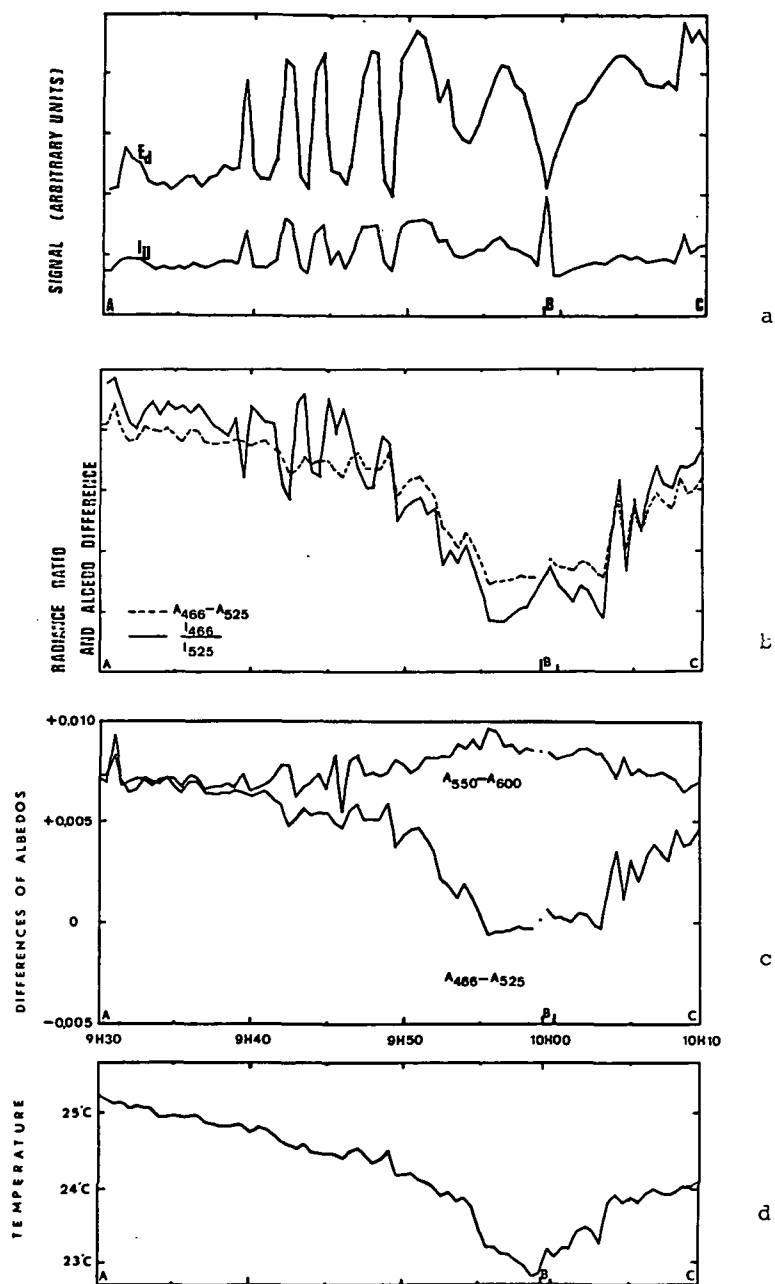


FIGURE 1. - FLIGHT RECORD 0930 to 1010 a.m., July 13, 1975

- a) Downwelling irradiance, E_d , and upwelling radiance I_u , at 466 nm.
- b) Comparison between ratio and difference methods at 466 nm and 525 nm.
- c) The two albedo differences $A_{466} - A_{525}$ and $A_{550} - A_{600}$.
- d) Sea surface temperature.

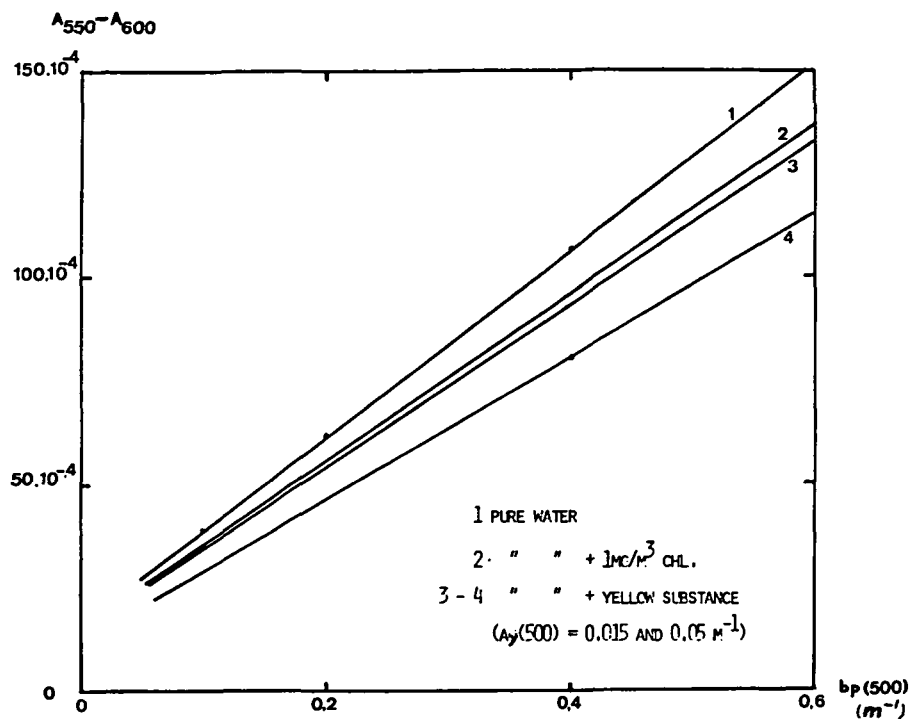


FIGURE 2. - Theoretical computation of the albedo difference $A_{550} - A_{600}$ as a function of the scattering parameter $b_p(500)$.

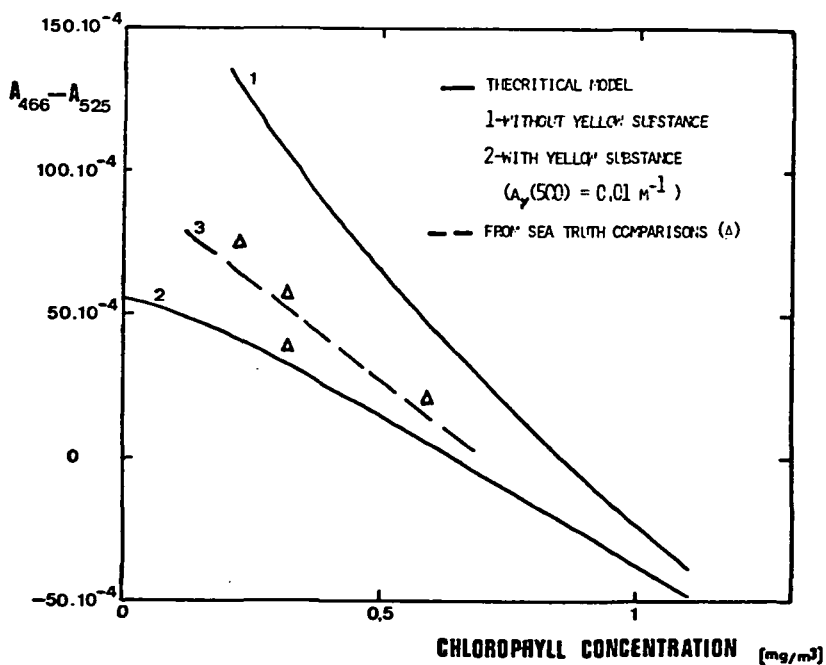


FIGURE 3. - Theoretical computation of the albedo difference $A_{466} - A_{525}$ as a function of chlorophyll concentration. Obtained sea truth comparisons are plotted by Δ .

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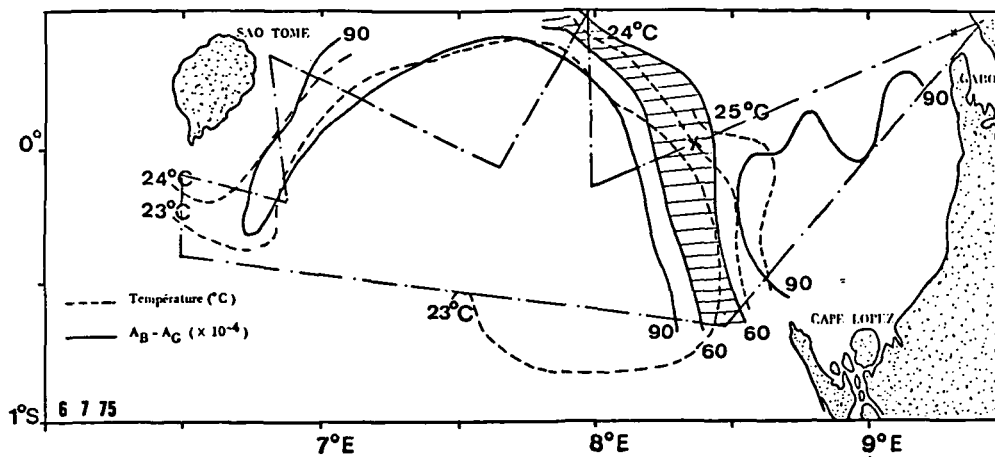


FIGURE 4.a.

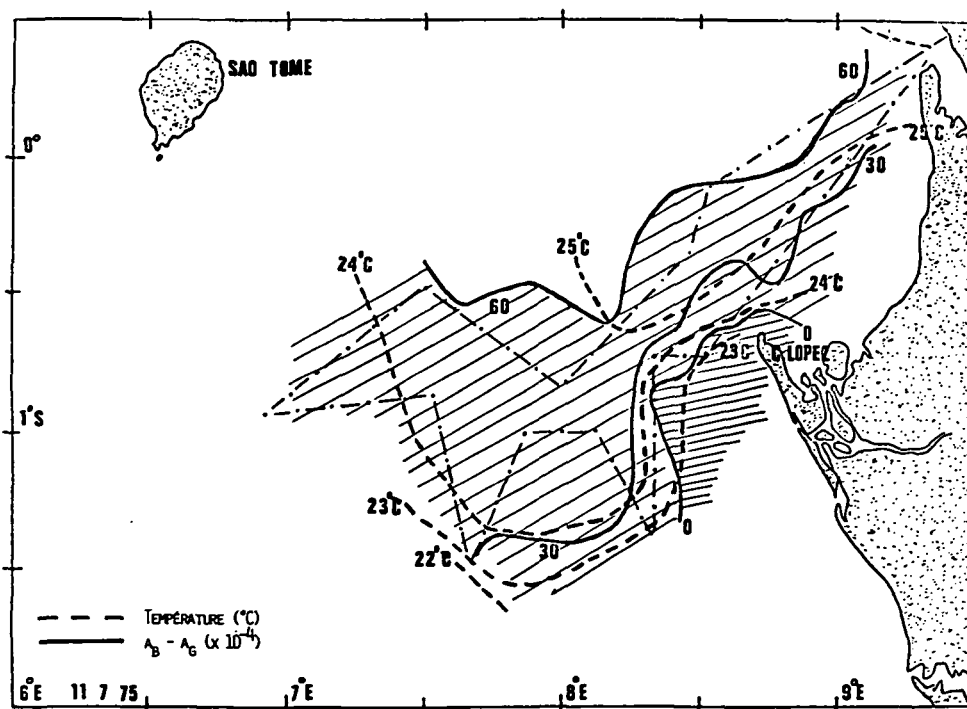


FIGURE 4.b.

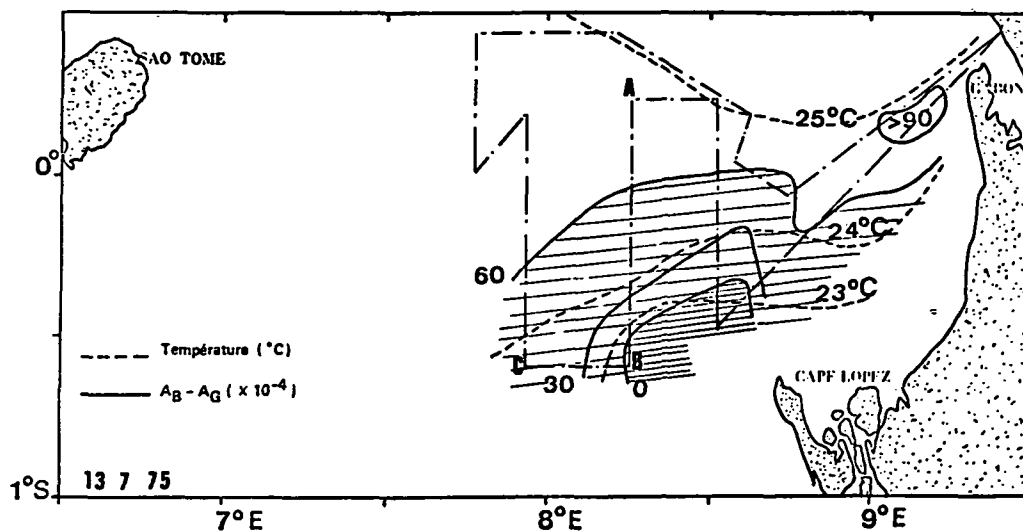


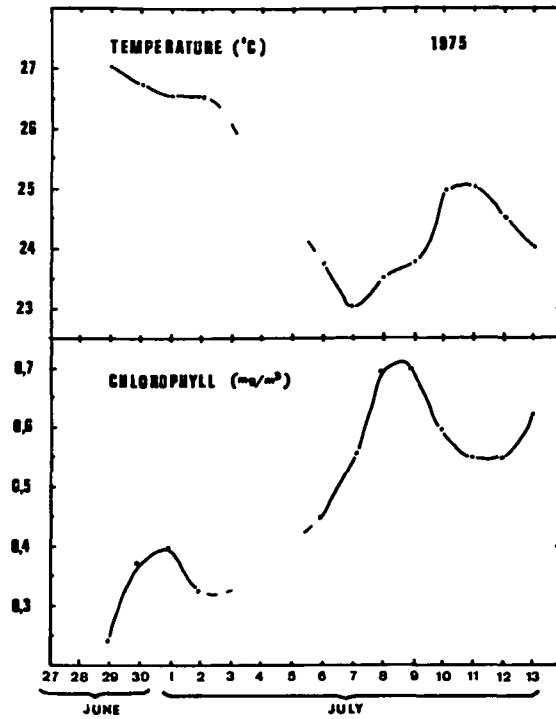
FIGURE 4.c.

FIGURE 4. - Sea surface isotherms and distribution of differences between blue and green albedos. Waters of moderate chlorophyll content ($0 < A_B - A_G < 60 \cdot 10^{-4}$) and of greater chlorophyll content ($A_B - A_G < 0$) are respectively the light and heavy shaded areas. Flight track is the dot dashed line.

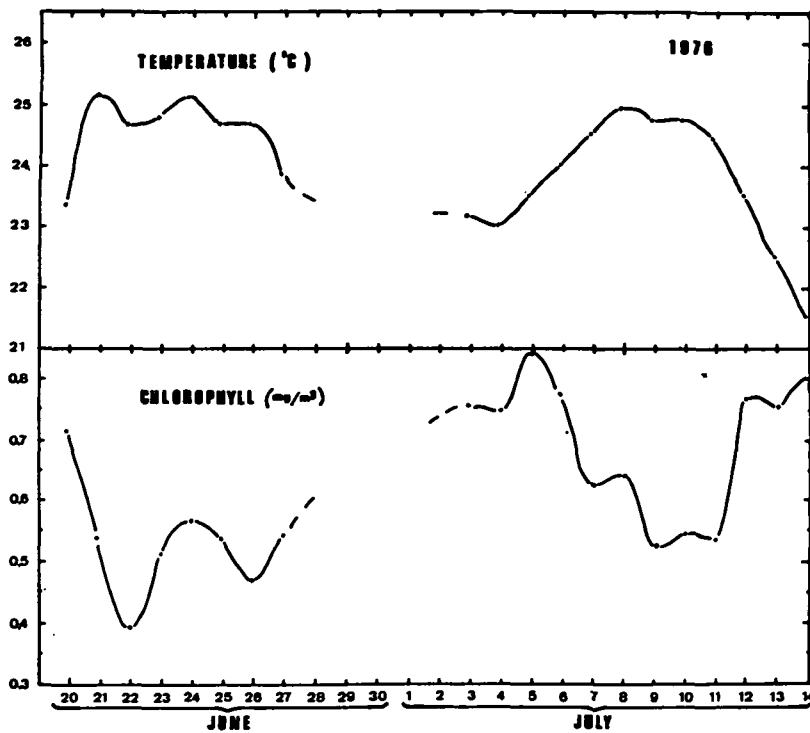
4.a. July 6, 1975

4.b. July 11, 1975

4.c. July 13, 1975



a



b

FIGURE 5. - Evolution of sea surface temperature and chlorophyll content as deduced from $A_{466} - A_{525}$, at point $0^{\circ}30'S$, $8^{\circ}E$ for June-July 1975, (a) and 1976, (b).

TEXTURAL ANALYSIS BY STATISTICAL PARAMETERS AND ITS APPLICATION
TO THE MAPPING OF FLOW-STRUCTURES IN WETLANDS

(MUDFLAT AREA AT THE GERMAN COAST OF THE NORTH SEA)

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ABSTRACT

For mapping the morphology in mudflat areas a digital texture analysis has been developed, by which measurement of the change of image-structures caused by disturbing factors like changing illumination will be possible.

1. INTRODUCTION

From 1974 until 1977 the application of remote-sensing methods in coastal areas and tidal bays and estuaries was investigated on the German coast of the North Sea. The Institute for Geography at the University of Munich, Section Remote Sensing, with its leader Prof. H. G. Gierloff-Emden took part in the investigations at the Jade in the north of the town Wilhelmshaven.

Responsible for the technical performance of these investigations was the DFVLR (Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt). Aerial photographs were taken using different films: color, color-infrared, black- and white films. Scanner-recordings were taken by an 11-channel-scanner (Bendix). Groundtruth-measurements of radiation and measurements of meteorological elements were carried out.

The task of the Institute for Geography at the University of Munich was to investigate how the change of morphologic phenomena can be recognized by application of methods of remote sensing and technics of image-enhancement. The investigated phenomena, described in this paper are flow-structures like banks and ripples. These structures are dependent of the grain-size of the sediment, the velocity of the streaming water and the shear-stresses.

Significant change of those structures can be caught hold of remote-sensing systems. To find out the reason of such changes ground-measurements have to be made. Together with groundtruth measurements on some suitable points the change of the conditions causing these structures can be mapped.

2. DISTURBING FACTORS WITH MAPPING FLOW STRUCTURES IN THE MUD-FLAT

Two images of the morphology of a mud-flat surface can be very different though there can be no difference in the surface of the mudflat at the two moments when the surface is recorded by the remote-sensing system.

When mapping the morphology of the mud-flat by that errors in the interpretation are possible. So it is necessary to investigate the most important disturbing effects, which are influencing the image of the mudflat-morphology taken by a remote-sensing system.

These effects are in detail the following:

1. The effect of different illumination

- a. caused by the amount of the angle between the line joining the object on the earth surface and the plane and the line which coincides with the direction of the maximal reflection of the object, where sun elevation is always the same,
- b. caused by the different sun elevation.

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These effects can be called as geometric disturbing effects.

2. The effect of changing the reflectance by the draining of the puddles on the mudflat by flowing off of the water and by drying up by evaporation.

This is a disturbing factor due to the object.

Because of these disturbing factors for morphologic interpretation of mudflat-images it is necessary to take a sequence with short time intervals, because the image of the morphology is a function of the dynamic process of the tides. To find out the change of the morphology during some weeks comparing of such two sequences of images is necessary.

There is now the question whether such disturbing factors can be eliminated or whether the disturbing factors are so characteristic, that identification of different types of ripple fields or bank fields is possible.

Therefore groundmeasurements of reflected radiation in the visible were made. Because of the problem of transportation exact measurements of radiation in different channels were not possible. The purpose of the measurements was the investigation of the reflectance of some little certain areas in bank and ripple fields in the mudflat in relation to different sun elevations. At each point measurements were made orthogonal down, 30° away and 30° against the sun. For each tested area characteristic differences of reflectance for the morphologic forms and the water puddles between them were found out. The differences changed that depends whether one have measured against the sun orthogonal down or with the sun. The reflection of the forms not covered with water was different and depends on the relief of the forms. Difference of reflection between the forms and the water puddles is normally so strong that inspite of loss of information an image structure is caused. The structures in images showing the same areas can be different because of the influence of the disturbing factors. These factors are determined by the reflection of the natural surface. Differences of this reflection dependent on sun elevation and the direction of measuring can be exactly found out on the ground. Differences in the image structure dependent on the factors 1., 2.a. and 2.b. can be quantitatively described only by a quantitative analysis of the image structure showing the interesting morphologic phenomena.

3. A METHOD OF TEXTURAL ANALYSIS FOR MORPHOLOGIC MAPPING WITH PARAMETERS DUE TO THE IMAGES OF THE SINGLE OBJECTS FORMING THE TEXTURE

3.1. TEXTURAL PARAMETERS

For solving the problem explained before the image structure has to be described by parameters which are connected with properties of the images of the single objects. So a description of the density-function $D(x, y)$ by a Fourier transformation is not convenient. There is the problem how to correlate the Fourier-coefficients with morphologic parameters.

Morphologic parameters in this case are e.g. length, height and width of banks or larger ripples or such forms, which can be identified in an image by texture. Because the image of an object cannot be identified exactly in such a case the image-object is defined in the following way: For each image-point the difference between its density-value and the mean of the density of this point and 8, 24, or 48 points around it is computed. So the density-plane of the whole image is cut with a smoothed density-plane. The complete areas consisting of pixels for which the difference between the density of the original image and the smoothed image is greater 0 should be called as "image-objects", the areas for which this difference is less 0 should be called as complementary image-objects.

If the density of each point of the smoothed image is computed from 9 points more little image-objects or complementary image-objects are received than the density of each point of the smoothed image is computed from 25 or 49 points.

The density of each image object is caused by the radiation reflected or emitted from the earth surface. So an image-object correlates with an object or a part of an object on the earth surface.

Are those objects banks or greater ripples the correlation is quite good and parameters of the image objects and the complementary image-objects are in relation with morphologic parameters.

So the first group of textural parameters consists of the following parameters:

- I) Distribution of the amount of the area, of the relation circumference/amount of area and of the length coefficient of the single image-objects of an image section. The length-coefficient is the linear correlation coefficient of the set of points belonging to one groundplan area of an image-object. In connexion with the computation of the correlation coefficient the direction of the correlation line is computed.

Characterizing the average form of the image objects in the direction of the density axis ($D(x, y)$) the group of the following parameters is computed:

- II) The distribution of the gradient vector $(dD/dx, dD/dy, 1)$ in the x, y -plane. The distribution of the gradient vector shows whether the variance of the density-values is high (the length of the gradient is large) or low (the length of gradient is small). Secondly one is interested in favored directions of the gradient vector. In supplement to this

distribution the correlation coefficient and the direction of the correlation line for the group of points destined by the gradient vector is computed. To avoid mistakes 1% of these points, these are the points for which the gradient vector has the greatest amount, are omitted. If the main direction of the gradient-vector and of the correlation-line are nearly the same, there would be in the image longer line-elements with high contrast otherwise, if the correlation line is orthogonal to the favored direction of the gradient-vector, there are no or only very short line-elements of higher contrast in the analysed image-section. In connection with the length of the gradient-vector and the size of the image objects is the distribution of the curvature of $D(x, y)$. The curvature can be computed in different ways, one of them is the computation of the La Place differential expression $d^2D/dx^2 + d^2D/dy^2$. Another possibility is to compute the mean of the angles between the tangential plane and $D(x, y)$ in a certain point, where for each point the angles are computed in 8 directions. If the angle is large the banks or ripples have a stronger relief.

At last the arrangement of the image objects in the aerial photograph or in the scanner-image has to be described:

III) For that the shortest distance between the main point of each two objects has to be destined. The distribution of these distances and the distribution of the direction of these distances correlates with the distribution of the shortest distances of each two banks and the distribution of the direction of these distances.

It is notable that the textural parameters are not characterized by numbers but by distributions except the correlation coefficient and correlation line in II. Characterizing the textures only by numbers is only possible by describing the distributions by their statistical parameters as mean and standard deviation. Loss of information can be avoided only, if the texture has a very regular structure.

3.2. THE PROBLEM OF INVARIANCE AGAINST ROTATION

The problem is that, if a texture analysis is made for two images, it is difficult to compare the results of the analysis, also if the same film was used. Differences in the results are not only caused by disturbing factors as described in 2. and other disturbing factors as different devellopping of the film, but caused by changing the scan direction when the image is digitalized. So all directions computed in I), II) and III) are dependent on rotation. But the effect of rotation can be eliminated very easily. For the remaining parameters invariance against rotation is very important. Change of the scanning direction causes changes of the scanning pattern. Because the scanning is rectangular, exact invariance against rotation is not possible. But for the parameters described in I) and III) the change, caused by rotation of the scanning direction is not significant if the solution of the scanning is high enough.

To compute the gradient-vector in an image-point (x, y) it is normally sufficient to draw on for the computation the 8 points around (x, y) . In extreme cases the rotation of the scanning direction causes differences of the length of the gradient, which have the factor $\text{SQRT}(2)$. In practical performance, when contrast is not extremely high the errors caused by rotation are not significant. The formula for the computation of the gradient is:

$$\text{grad}(x_0, y_0) = \text{nabla} \cdot D(x, y) = (dD/dx, dD/dy, 1) = (sx_0, sy_0, 1)$$

with

$$sx_0 = ((sx_{-1,1} - sx_{1,-1}) + 2 \cdot (sx_{-1,0} - sx_{1,0}) + (sx_{-1,-1} - sx_{1,1}))/4$$

$$sy_0 = ((sy_{1,-1} - sy_{-1,1}) + 2 \cdot (sy_{1,0} - sy_{-1,0}) + (sy_{1,-1} - sy_{-1,-1}))/4$$

where the points (x_i, y_i) are arranged in the following way:

$$\begin{array}{ccc} x_{-1,1} & x_{0,1} & x_{1,1} \\ \cdot & \cdot & \cdot \\ x_{-1,0} & x_{0,0} & x_{1,0} \\ \cdot & \cdot & \cdot \\ x_{-1,-1} & x_{0,-1} & x_{1,-1} \\ \cdot & \cdot & \cdot \end{array}$$

The La Place expression is computed to:

$$sx_0^2 + sy_0^2,$$

where in the first equation above sx must be replaced by $s\hat{x}$ and in the second sy by $s\hat{y}$.

In exceptional cases a better approximation for computing the gradient is necessary. 21 points have to be drawn on, which are arranged in the following way:

$$\begin{array}{ccccc} \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & x & \cdot & \cdot \\ \cdot & x & \cdot & x & \cdot \\ \cdot & \cdot & x & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \end{array}$$

iii. LENGTH COEFFICIENT

0	1	0	89	6	8	7	5	8	9	12	17	39	
-1.0	-0.2	-0.1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

corr. coeff.

mean: 0.3953 stand.dev.: 0.40749

The mean of the direction of the correlation line is 25.6°, the standard deviation is 22.7°.

b. COMPLEMENTARY IMAGE-OBJECTS TOTAL: 123

i. AMOUNT OF AREA

90	15	6	3	4	0	1	0	0	1	1	0	0	1	1	0	
0	10	20	30	40	50	60	70	120	130	140	230	240	250			pixel

mean: 13,98374 standard deviation: 34.61753

ii. RELATION CIRCUMFERENCE/AMOUNT OF AREA

0	0	5	16	9	15	9	10	8	0	14	0	0	0	0	37	
1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	circ./am. of area

mean: 2.75949 standard deviation: 0.90217

iii. LENGTH COEFFICIENT

0	1	1	40	6	4	5	4	3	8	5	11	35	
-1.0	-0.2	-0.1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

mean: 0.48402 standard deviation: 0.41442

The mean of the direction of the correlation line is 28.7°, the standard deviation is 24.0°.

GROUP II:

i. LENGTH OF THE GRADIENT VECTOR

455	963	795	563	334	166	57	13	3	4	0	1	1	0	2	0	0	3	1	0	
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

1

0

1

1

2021222324

• 10⁻¹ mm

mean: 2.65101

standard deviation: 1.70299

ii. DIRECTION OF THE GRADIENT VECTOR

116	139	88	100	170	95	96	99	52	120	99	59	49	142							
-180	-170	-160	-150	-140	-130	-120	-110	-100	-90	-80	-70	-60	-50	-40						
69	73	87	45	170	113	91	104	187	107	95	88	112	52	85	46	64	95	52		
-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	
73	74	58																		
150	160	170	180	(°)																
mean: -103,5°				standard deviation: 51,0°																

iii. CURVATURE ANGLE

1	0	9	28	45	61	55	75	82	108	109	128	117	148	153							
-180	-170	-160	-150	-140	-130	-120	-110	-100	-90	-80	-70	-60	-50	-40	-30						
182	167	144	205	189	172	152	192	135	151	115	121	93	73	62	48	26	12	5	0	1	
-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180 (°)

mean: 0.2° standard deviation: 68.3°

iiii.

correlation coefficient -0.99797
direction of correlation line: -0.096°

GROUP III.

i. SHORTEST DISTANCES BETWEEN THE OBJECT IMAGES

4	50	81	49	15	1	1	
0	1	2	3	4	5	6	7

mean: 2.58133 standard deviation: 0.87958

ii. DIRECTION OF THE SHORTEST DISTANCES

6	13	14	7	22	10	4	10	8	11	10	15	8	22	11	7	11	2	10
-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90

mean: -1.5° standard deviation 51.7°

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SECTION 2:

GROUP I:

a. IMAGE OBJECTS TOTAL: 144

i. AMOUNT OF AREA

116	15	2	4	3	0	1	0	0	1	1	0	1		
0	10	20	30	40	50	60	70	80	90	100	110	490	500	pixel

mean: 11.0625 standard deviation: 42.84034

ii. RELATION CIRCUMFERENCE/AMOUNT OF AREA

0	13	9	14	12	10	11	0	19	0	56
1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	4.0	

mean: 2.98244 standard deviation: 0.88687

iii. LENGTH COEFFICIENT

0	56	0	10	78
0	0.1	0.8	0.9	1.0

mean: 0.58993 standard deviation: 0.47190

The mean of the direction of the correlation line is 27.5° , the standard deviation is 21.9° .

b. COMPLEMENTARY IMAGE OBJECTS: TOTAL: 152

i. AMOUNT OF AREA

102	28	8	4	4	0	3	1	1	1		
0	10	20	30	40	50	60	70	80	90	100	PIXEL

mean: 10.91447 standard deviation: 16.01359

ii. RELATION CIRCUMFERENCE/AMOUNT OF AREA

0	2	10	23	10	20	8	14	9	0	16	0	40
1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	4.0	

mean: 2.64037 standard deviation: 0.91308

iii. LENGTH COEFFICIENT

40	0	12	100	
0	0.1	0.8	0.9	1.0

mean: 0.70945 standard deviation: 0.42576

The mean of the direction of the correlation line is 33.2° , the standard deviation is 19.8° .

GROUP II:

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i. LENGTH OF THE GRADIENT VECTOR

339	1007	892	636	306	117	54	4	3	0	2	3	0	1	
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14

mean: 2.60724 standard deviation: 1.35432 $\cdot 10^{-1} \text{ mm}$

ii. DIRECTION OF THE GRADIENT VECTOR

123	104	97	125	156	111	98	108	53	128	76	54	62	111	61	50	93	59	164	114	
-180	-170	-160	-150	-140	-130	-120	-110	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20
105	133	150	115	111	98	110	44	79	65	56	120	49	59	79	44					
20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180				

mean: 77,0° standard deviation: 50.4° (°)

iii. CURVATURE ANGLE

0	0	1	8	33	47	65	85	105	113	122	139	124	154	153	175	170	135	193	176	203	
-180	-170	-160	-150	-140	-130	-120	-110	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30
165	155	127	152	133	118	94	75	56	42	29	11	3	2	1							
30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	(°)					
mean: 0.2° standard deviation: 67.2°																					

iiii.

correlation coefficient: 0.92443
direction of correlation line: 0.14285°

GROUP III:

i. SHORTEST DISTANCE BETWEEN COMPLEMENTARY OBJECT IMAGES

Because the number of complementary object images is greater than the number of object images, the shortest distance between the complementary object images is computed.

0	19	53	53	16	6	5	
0	1	2	3	4	5	6	7

mean: 3.14186 standard deviation: 1.20905 $\cdot 10^{-1} \text{ mm}$

ii. DIRECTION OF THE SHORTEST DISTANCES

9	13	10	5	13	11	4	6	14	8	6	5	13	5	4	6	14	2	4
-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90

mean: 1.47968 standard deviation: 52.44994° (°)

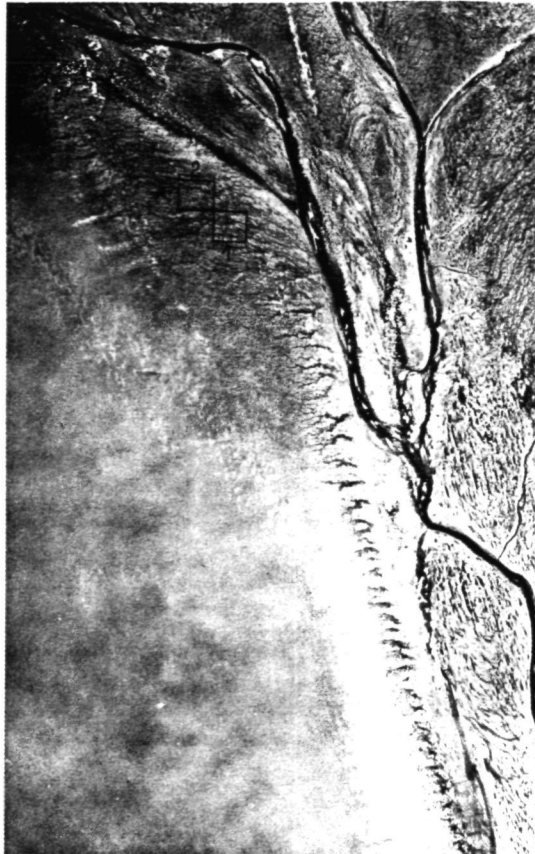
There are differences between the parameters of group I. The scanned aerial photograph was a color infrared negative. So water has very low density values and correlate with the complementary image objects. The image objects correlate with the banks. In section 1 there are more image objects than in section 2 and less complementary image-objects than in section 2. The area shown in section 1 lies deeper and nearer to the tidal creek as the area shown in section 2. On the mudflat of section 1 the quantity of water is greater, the part of the banks which do not ly under water are smaller than on the mudflat in section 2. In section 1 the banks are more isolated and many water puddles are joined together, so that the number of complementary image-objects is smaller and the complementary image objects are greater on the average. The length coefficient for section 2 is nearer to 1 because little creeks orthogonal to the banks are formed. For the parameters of group II there is only a difference for the direction of the gradient. This difference is about 180°. This difference is probably caused by a stronger inclination of the surface shown in section 1 to the sun (to the right in fig. 1), so that the effect of shadow is stronger in section 2. The differences for the parameters of group III have the same reason as the differences for the parameters of group I.

This example shows that the parameters correlate with properties of the mudflat surface. The conclusions done before are confirmed by investigations on the ground.

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Fig.1: A section of the mudflat area in the North of Wilhelmshaven
near Crildumersiel, scale 1:8000.

PRODUCTION OF A WATER QUALITY MAP OF SAGINAW BAY

BY COMPUTER PROCESSING OF LANDSAT-2 DATA

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ABSTRACT

Surface truth and LANDSAT measurements collected July 31, 1975 for Saginaw Bay are used to demonstrate a technique for producing a color coded water quality map. On this map, color is used as a code to quantify five discrete ranges in the following water quality parameters: temperature, Secchi depth, chloride, conductivity, total Kjeldahl nitrogen, total phosphorous, chlorophyll a, total solids and suspended solids.

The LANDSAT and water quality relationship is established through the use of a set of linear regression equations where the water quality parameters are the dependent variables and LANDSAT measurements are the independent variables.

Although the procedure is scene and surface truth dependent, it provides both a basis for extrapolating water quality parameters from point samples to unsampled areas and a synoptic view of water mass boundaries over the 3000 km² bay area made from one day's ship data that is superior, in many ways, to the traditional machine contoured maps made from three day's ship data.

1. INTRODUCTION

Since June of 1974 the Bendix Aerospace Systems Division has been conducting a research program in the surveillance from LANDSAT of eutrophication in Saginaw Bay, Michigan and in the inland lakes and watersheds of Michigan and Wisconsin. This paper addresses the development of one specific water quality map of Saginaw Bay.

The EPA-sponsored study of water quality in Saginaw Bay (Lake Huron) aims to describe, on a seasonal basis, the distribution of water quality factors in the Bay; to monitor inputs of nutrients from its watershed; and to develop and evaluate models for predicting water quality in the Bay as a function of various control strategies (Reference 1 and 2). A surface/subsurface measurement program has been underway since April 1974. From each of 59 stations distributed throughout Saginaw Bay, some 30 water quality parameters are determined on an 18-day cycle that coincides with the LANDSAT over-flights. During 1974 and 1975 32 cruises were made.

Saginaw Bay is a shallow extension of Lake Huron and is bounded by five counties of southeastern Michigan (Figure 1). The bay has an area of some 2,960 km² and a maximum length and width of 82 km and 42 km, respectively. The mean depths are 4.6 m for the inner bay and 14.6 m for the outer bay. The Saginaw River enters the bay at its extreme southwestern end and contributes approximately 90% of the pollutants found in the bay (Reference 3). This river and its tributaries drain a watershed of more than 21,000 km² that contains four major

cities and much agricultural land. Consequently, inputs of salts, nutrients, and pollutants to the bay have been increasing for many years. Levels of turbidity and algal production are consistently high, especially within the inner bay. Major declines in commercial fish yields, wildfowl populations, and esthetic values have resulted from this eutrophication. In addition, the natural estuarine-like movement of pollutants from the bay into southern Lake Huron may reduce water quality throughout the lower Great Lakes.

The purpose of this and earlier efforts was twofold: 1) to use LANDSAT to produce a color map delineating water masses within the bay, and, more importantly, to relate the water masses so delineated to quantitative levels of water quality. The first level of mapping requires no surface truth measurements and can be done with a minimal amount of computer processing. The second level of mapping, however, requires detailed surface truth and a number of computer processing steps but provides a significant increase in the information content and its effective presentation. The procedure reported here was determined to be the most efficient and productive of the approaches investigated.

2. TECHNIQUE

The data processing procedure used to produce the water quality map of Saginaw Bay can be described as a number of steps.

Step 1. Ship Data Collection. Three consecutive days are required to sample all the bay stations. For the maps produced in this study only those surface samples taken the same day as the overpass, from 16 of the 59 stations, were used (Figure 1 and Table 1).

Step 2. Geometric Correction. LANDSAT-2 computer compatible tapes for two consecutive scenes, acquired on 31 July 1975 (2190-15401 and 2190-15404), were processed on a Bendix MDAS (Multispectral Data Analysis System). The satellite data were first geometrically controlled by digitizing ground control points (GCPs) such as prominent coastal features, from a navigation chart. The latitude and longitude of each GCP was converted to LANDSAT coordinates using an interactive display routine on MDAS, and a geometric transformation matrix was established for the greater bay area. The bay station coordinates were transformed to LANDSAT coordinates with an error of less than one picture element (pixel). A LANDSAT pixel corresponds to an area of 57 by 79 m (0.44 hectares).

Step 3. LANDSAT Data Sampling. The established geometric correction matrix and the MDAS TV monitor were used to display the single pixel best corresponding to the digitized location of each bay station. A cursor was then positioned, expanded, and shaped by the operator about each station site to designate a station area of 60 to 100 pixels in size. Once the station areas were designated, the MDAS computer extracted the measurements from all pixels defined by the cursor and calculated the mean digital count in each band (Table 2).

Step 4. Regression Analysis. A variety of regression analyses were made. In all cases a linear regression was used and LANDSAT radiance measurements in the four bands were treated as the independent variable while the surface truth data were treated as the dependent variables. Earlier work showed that with stepwise multiple regression analysis: 1) the use of a ratio of bands does not improve the strength of the correlation over the use of single bands, and 2) bands 4 and 5 provide more information than bands 6 and 7. Accordingly, in this effort only data from bands 4 and 5 were entered into the analysis. The regression equations are shown in Table 3 and parameter range correlation coefficients and standard error of estimate are shown in Table 4.

Step 5. Review of LANDSAT Data. This important step provides the basis for applying the relationship derived in step 4 back to the LANDSAT data for the entire bay. The bay was screened in both false color and single channel levels slice mode on MDAS to determine how many distinct water masses or zones were present. Five such levels of water quality were identified. The mean radiance of training sets for each of these five areas (categories) was computed by MDAS. A color code was assigned to each category at this time (Table 5). The parameter value associated for each color (Table 6) was calculated by putting the appropriate training set means back into the equations derived in Step 4 (Table 3).

Step 6. Processing and Filming. With training sets identified in Step 5 the entire bay was categorized and the result was output on the MDAS drum film recorder. Geometric corrections were automatically applied during filming.

3. DISCUSSION

The results of this technique have been evaluated by inspection of graphs and tabular data, by inspection of map features and by comparison with another technique.

Figure 2 is a representative plot of many that were constructed to graphically summarize the performance of the regression analysis. In this example, chlorophyll a, it shows that all but 3 of the 16 predicted sample values fall within one standard deviation of their measured value.

Table 7 was prepared to aid in the explanation of the physical relationship between the LANDSAT data and the water quality values. It should be emphasized that LANDSAT measures color or volume reflectance of the water and does not, for example, measure temperature, chloride, conductivity, etc. directly. Only a few water quality parameters; chlorophyll a, suspended solids, turbidity, and Secchi depth, have a direct influence on the color or volume reflectivity of Saginaw Bay water. However, the other water quality parameters do correlate secondarily with color or volume reflectance to the extent that they all characterize the same water masses (Table 7).

Analysis of the final map (Figure 3) has confirmed some known features of circulation and water quality in Saginaw Bay. Previous surveys of the bay (Reference 1 and 3) have indicated that the predominant flow of Saginaw River water is northward along the eastern shore of the bay. Less turbid Lake Huron water dominates the outer bay and enters the inner bay chiefly along the western shore. Zones of mixing and local circulation are apparent on the map, as are shoal areas where sediment evidently has been resuspended.

The Saginaw River enters Saginaw Bay at its extreme southwestern end and contributes the majority of pollutants found in the Bay. The magenta color, which represents levels of water quality that are beyond the range of the sample data used in the regression program, enhances the plume of turbid water that enters the Bay from the Saginaw River and extends in a southeast direction. In the shallow near-shore zone (less than about ten feet deep) of the lower bay, the magenta denotes areas where there is significant local resuspension of sediment.

A lobe of relatively clean Lake Huron water (blue) appears to enter the mouth of the Bay between a central island (Charity Is.) and a coastal point (Lookout Pt) and flow up the Bay (south) along its deepest channel. The boundary of the lobe and the Bay water (green) is very pronounced and not gradational as is the case with the remaining three water mass boundaries.

A third feature is the spiral of water masses just northeast of the "thumb" of Michigan. This is an apparent mixing zone of turbid water that has been transported from the Bay into Lake Huron. The transporting current may have been set up by the counterclockwise deflection of southward moving Lake Huron water, along the shallow area between Charity Island and the eastern shore of the Bay mouth (Oak Pt.). Thus one mass of Lake Huron water enters the Bay along its western shore while another mass is prevented from entering but helps transport turbid bay water into Lake Huron. The apparent increase in turbidity at the top right corner of the map is due to the presence of an atmospheric haze associated with clouds, about 25 km northeast of the right corner of the map, but within the full scene.

The nine water quality parameters were mapped as one map. If separate maps were required for each parameter the breaks between color levels could be relocated so as to better proportion the levels. For example, the map shown here indicates that chlorophyll a is low in the outer bay and central portion of the inner bay but extremely high in the near shore zone of the inner bay. A separate map, made with different training areas, could be made for each parameter. In the case of chlorophyll a this would permit perhaps one color code for the areas of low concentration and four colors for the areas of high concentration as opposed to three and two respectively.

A comparison between the LANDSAT derived water quality map and those produced by another technique, but for the same surface truth measurements, provides for further evaluation of this technique. The EPA commonly makes machine plotted contour maps for areas such as Saginaw Bay from station data that is filed in the EPA-STORET system. Figure 4 is a copy of one such map for Chloride and shows the 16 stations, the parameter values at each station, and the computed contour lines. Figure 5 is a copy of the Chloride map for 3 days of ship data with shading to reflect the same levels of water quality that are shown in Figure 3. The boundary values of the shaded areas correspond to mid range values as determined from Table 6. A

comparison of Figure 4 with Figure 5 shows that plotter maps of one day's data do not provide an accurate synoptic portrayal of bay water quality. Figure 3 compares very favorably with Figure 5 but the LANDSAT technique provides a much more detailed portrayal that is more realistic in pattern than that provided by the machine plotter technique. Figure 6 is shown to provide further comparison with one additional water quality parameter Secchi depth. One conclusion of this comparison of techniques is that a water quality map derived from the computer processing of LANDSAT data and one day's surface truth provides as much, if not more, detail than a water quality map made from the machine contouring of three days surface truth. If the LANDSAT derived map meets the standards and needs set up by the water quality researcher then in subsequent studies the three day ship survey cruise could be shortened to one day at a significant cost savings.

It should be emphasized that the equations used to relate the water quality measurements with the LANDSAT data are scene and surface truth dependent. Atmospheric conditions can be extremely variable with time over the bay region and, in addition, the relationship of water quality to radiance may vary. Thus, this technique would have to be repeated from processing LANDSAT data of a different date.

4. ACKNOWLEDGEMENTS

Many individuals contributed to this project, while space does not permit identifying each the efforts of William L. Richardson of the U.S. EPA Large Lakes Research Station, in providing the contour maps, and Navin J. Shah, of Bendix for developing special software and facilitating data handling are acknowledged.

5. SUMMARY

Computer processed LANDSAT data can be color keyed to water quality parameters by a procedure using linear regression equations and surface truth measurements. Although the procedure is scene and surface truth dependent it establishes a relationship with a predictable accuracy. The resulting color-keyed map shows the concentration and distribution of water quality parameters throughout Saginaw Bay. The parameters need not be directly detectable by LANDSAT, provided their concentration is correlated with some water characteristic that is detectable. LANDSAT when used in conjunction with conventional point-sampling provides an economical basis for extrapolating water quality parameters from point samples to unsampled areas and provides a synoptic view of water mass boundaries that no amount of point sampling could provide.

Application of non-linear regression analysis and techniques for correcting LANDSAT data for atmospheric effects should decrease the standard error of estimate in predicting water quality parameters and result in the possible further reduction of surface sampling. These steps and work with data of different dates may help to further the goals of the EPA in their effort to study the circulation of water masses and model the water quality of Saginaw Bay.

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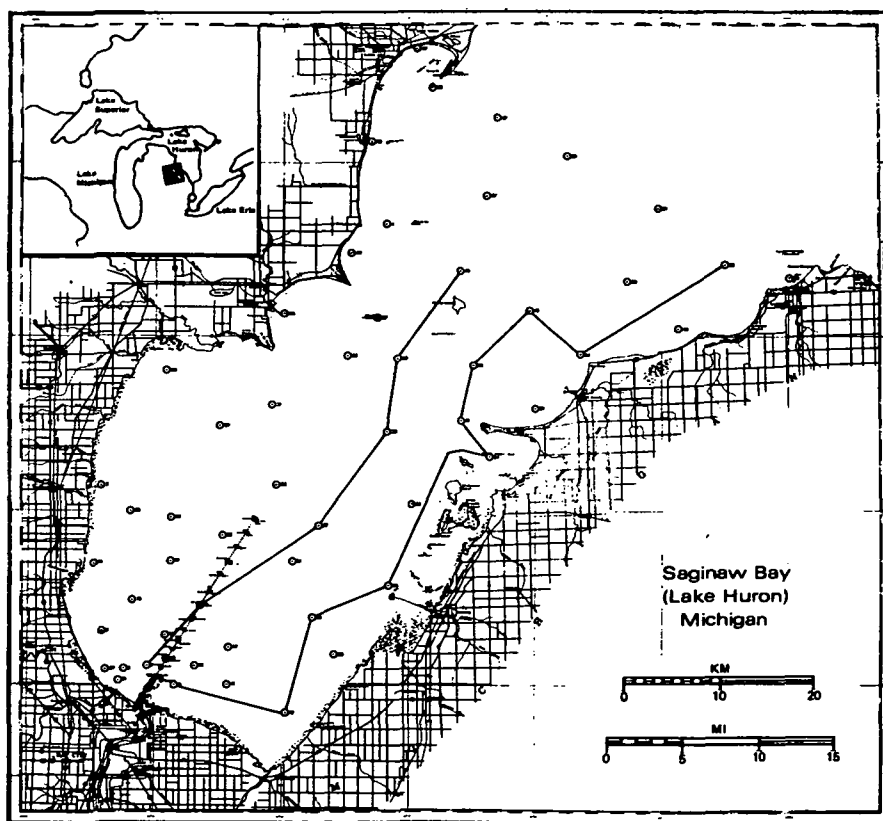


Figure 1. Map of Saginaw Bay, Showing the 61 Water Quality Stations by the Symbol $\odot$. The Cruise Tracks of the Two Vessels and the 16 Stations Sampled on the Day of the LANDSAT Overpass (31 July 1975) are also Shown.

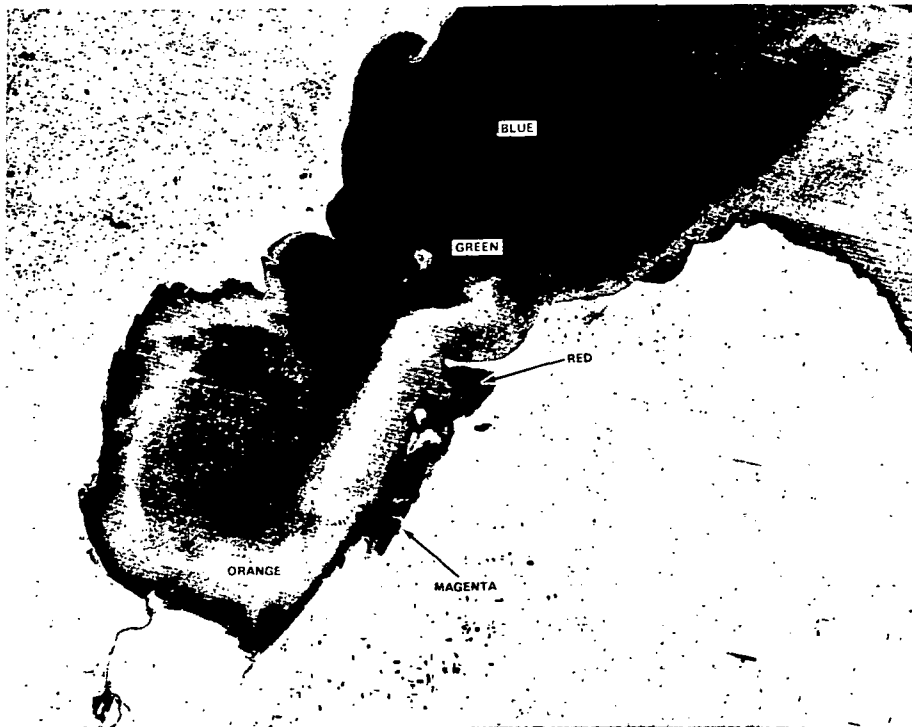


Figure 3 Water Quality Map Made From LANDSAT and Ship Data From 16 Stations, July 31, 1975

CHLORIDE
1 Days Ship Data

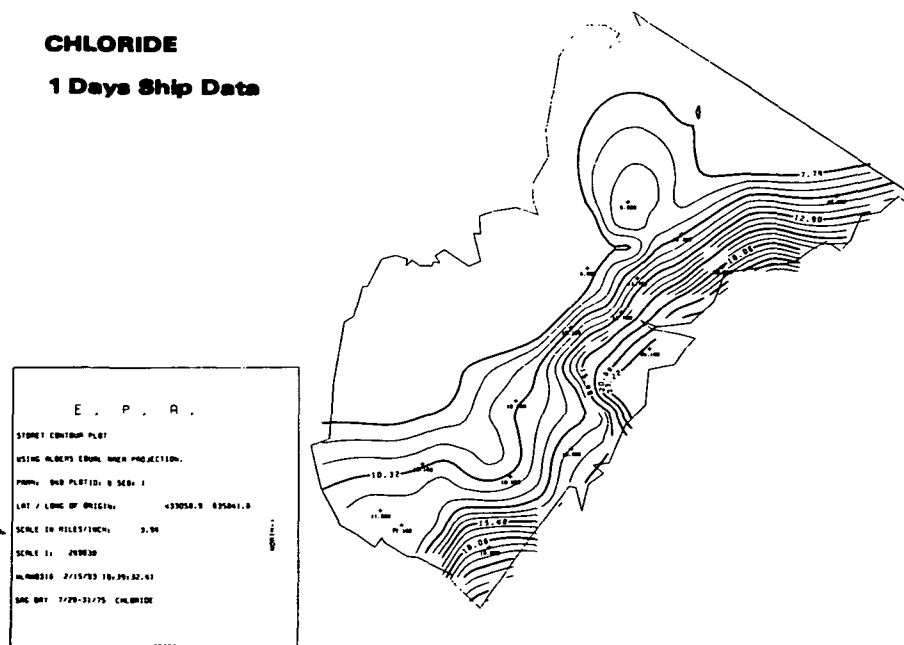


Figure 4 Machine Contoured Chloride Data, 16 Stations, July 31, 1975

CHLORIDE
3 Days Ship Data

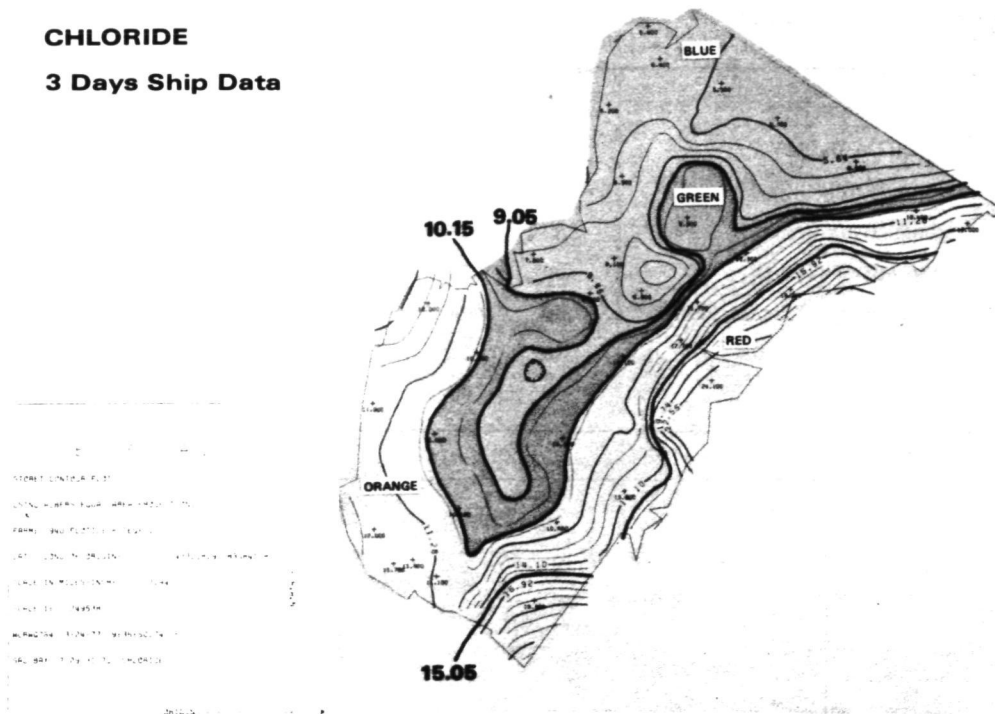


Figure 5 Machine Contoured Chloride Data,
33 Stations, July 29-31, 1975

SECCHI DEPTH
3 Days Ship Data

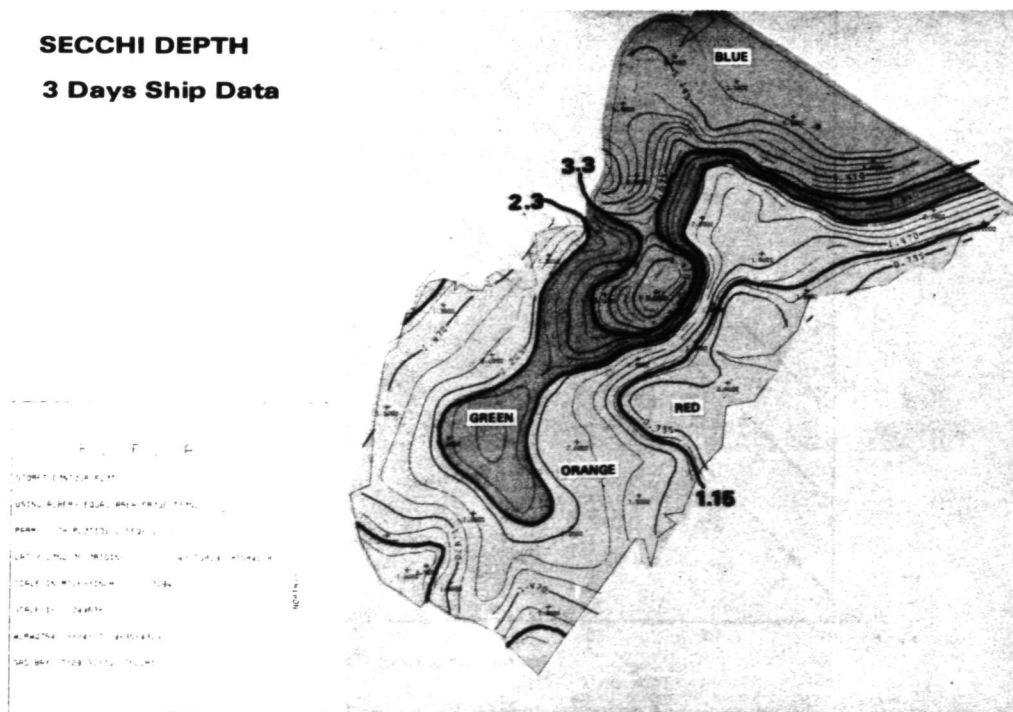
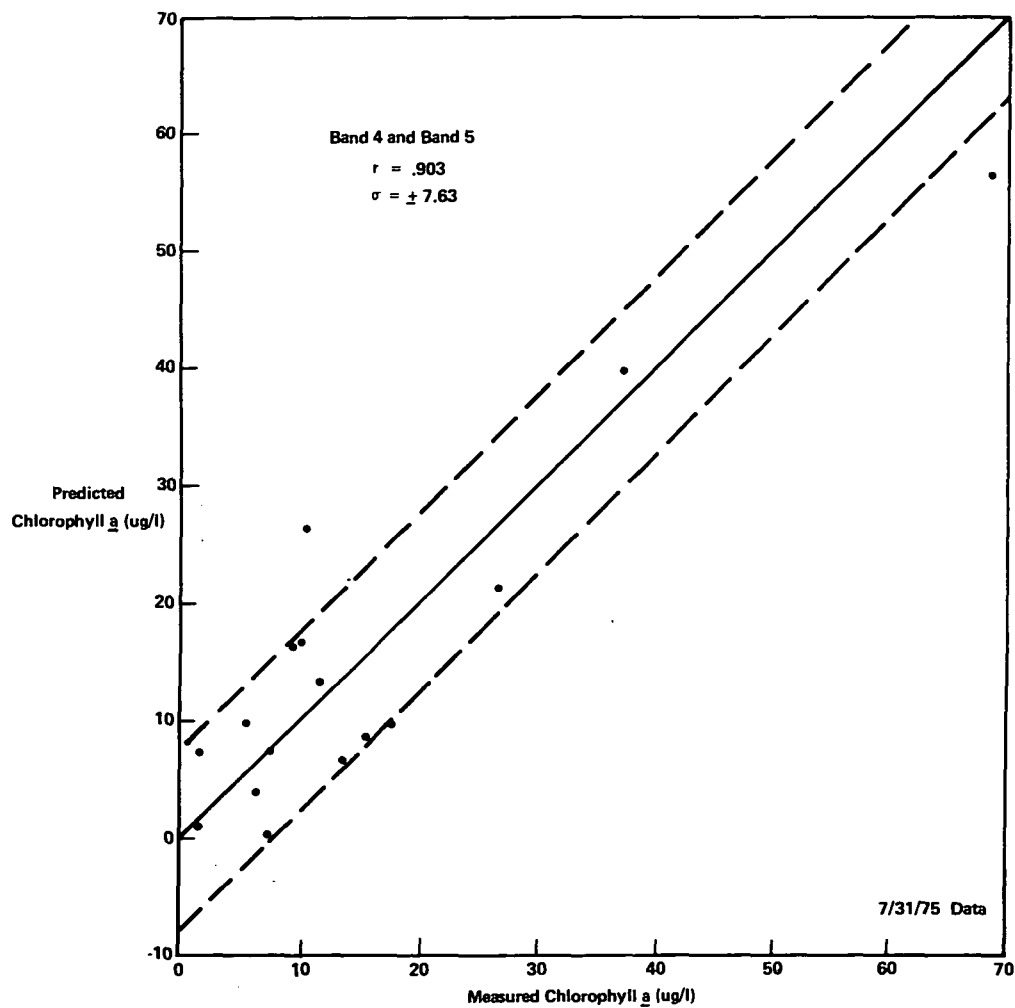


Figure 6 Machine Contoured Secchi Depth Data,
33 Stations, July 29-31, 1975

Table 7

Correlation Coefficient Matrix (59 Stations)

Temperature (T)	1.00				Cruise 25 July 29 - 31, 1975		
Secchi Depth (SD)	-.76	1.00					
Chloride (Cl)	.48	-.54	1.00				
Conductivity (Con)	.47	-.54	.99	1.00			
Chlorophyll <u>a</u> (Ch <u>a</u>)	.54	-.67	.41	.37	1.00		
Total Kjeldahl Nitrogen (TKN)	.59	-.66	.94	.92	.61	1.00	
Total Phosphorus (TP)	.39	-.50	.98	.98	.39	.91	1.00
	T	SD	Cl	Con	Ch <u>a</u>	TKN	TP

Figure 2 Predicted Versus Measured Chlorophyll a

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Table 1

EPA Water Quality Data For Saginaw Bay, 31 July 1975.
Measurements were Made At Water Depth Of One Meter

Station	Temperature (°C)	Secchi Depth (m)	Chloride (mg/l)	Conductivity (micromhos)	Total Kjeldahl Nitrogen (mg/l)	Total Phosphorus (mg/l)	Chlorophyll $\bar{a}$ (μ g/l)
7	26.1	1.9	10.9	243.	0.37	0.012	20.70
8	26.7	1.6	11.1	258.	0.41	0.017	9.38
12	26.8	1.3	18.8	277.	0.65	0.027	10.70
18	23.6	2.0	9.8	237.	0.38	0.012	5.61
26	26.0	1.6	13.8	251.	0.35	0.018	11.60
27	23.7	2.0	10.1	239.	0.29	0.012	7.38
32	24.8	1.8	10.1	235.	0.33	0.010	7.38
34	26.9	10.6	24.1	294.	1.00	0.039	68.50
38	25.1	1.4	11.7	244.	0.29	0.014	13.60
42	20.4	5.5	6.6	211.	0.14	0.002	1.84
43	23.5	1.5	12.1	246.	0.42	0.013	15.60
44	24.4	1.0	20.1	281.	0.72	0.027	37.10
52	21.5	2.1	10.4	238.	0.33	0.009	10.00
56	23.7	2.2	10.6	244.	0.26	0.014	6.58
60	22.5	5.0	6.9	215.	0.17	0.004	1.84
61	25.7	1.2	12.7	252.	0.42	0.020	18.00
Mean	24.46	2.0	12.5	247.8	0.41	0.016	15.36
Std. Dev.	1.92	1.3	4.7	21.8	0.22	0.009	16.53

Table 2

LANDSAT Data For Saginaw Bay, 31 July 1975

Station	Number of Pixels to Station Area	Mean Reflectance of Station Area			
		Band			
		4 254*	5 254*	6 254*	7 252*
7	56	40.6	27.5	14.8	1.4
8	63	44.0	29.5	16.3	1.5
12	72	42.8	29.5	16.2	1.7
18	72	38.1	24.7	13.8	0.5
26	64	42.7	28.3	14.7	0.4
27	90	38.1	24.5	12.2	0.3
32	100	37.2	23.2	11.7	0.1
34	100	38.6	29.1	16.4	0.9
38	121	40.4	26.1	12.3	0.1
42	72	32.3	20.3	9.8	0.3
43	72	36.0	23.1	10.9	0.2
44	72	35.6	25.5	14.5	0.8
52	72	32.3	21.1	11.0	0.4
56	72	39.5	25.2	12.8	0.6
60	110	34.0	21.0	10.1	0.1
61	99	43.7	28.7	14.1	0.6
Mean	81.7	38.5	25.4	13.2	0.6
Std. Dev.		3.8	3.1	2.2	0.5

*Maximum pixel count.

Table 3

Regression Equations For
Saginaw Bay 7/31/75 (16 Samples)

Temperature (°C)	= 9.61 + 0.007 (Band 4) + 0.572 (Band 5)
Secchi Depth (m)	= 8.24 + 0.142 (Band 4) - 0.458 (Band 5)
Chloride (mg/l)	= 9.489 - 2.040 (Band 4) + 3.202 (Band 5)
Conductivity (micromhos)	= 194.2 - 7.72 (Band 4) + 13.79 (Band 5)
Total Kjeldahl Nitrogen (mg/l)	= 0.419 - 0.102 (Band 4) + 0.153 (Band 5)
Total Phosphorus (mg/l)	= -0.0069 - 0.0033 (Band 4) + 0.0059 (Band 5)
Chlorophyll $\bar{a}$ (μ g/l)	= 41.04 - 8.32 (Band 4) + 11.57 (Band 5)
Total Solids (mg/l)	= 154.1 - 7.73 (Band 4) + 12.93 (Band 5)
Suspended Solids (mg/l)	= 0.908 - 1.02 (Band 4) + 1.67 (Band 5)

Table 4

Regression Results For Saginaw Bay 7/31/75 (16 Samples)

Water Quality Parameter and Range	Regression Correlation Coefficient	Standard Error of Estimate
Temperature (20 - 27°C)	.94	0.68
Secchi Depth (0.6 - 5.5 m)	.73	0.97
Chloride (6 - 24 mg/l)	.92	1.9
Conductivity (211 - 294 micromhos)	.93	8.6
Total Kjeldahl Nitrogen (0.1 - 1.0 mg/l)	.94	.08
Total Phosphorus (0.002 - 0.039 mg/l)	.94	.0035
Chlorophyll <i>a</i> (1.8 - 68.5 ug/l)	.90	7.6
Total Solids (150 - 244 mg/l)	.79	15.
Suspended Solids (1 - 13 mg/l)	.74	2.3

Table 5
LANDSAT Training Set Means

Color	4	5	6	7
Blue	30.3	18.9	9.5	0.2
Green	36.7	23.5	11.6	0.2
Orange	41.6	26.8	14.2	1.2
Red	42.7	30.4	17.2	3.1
Magenta	45.6	37.8	25.1	6.8

Table 6

Explanation Block For The Water Quality Map (Figure 3)

	Blue	Green	Orange	Red	Magenta	Standard Error of Estimate
Temperature (°C)	20.6	23.3	25.2	27.3	31.6*	1.6
Secchi Depth (m)	3.9	2.7	1.9	0.4	< 0.4*	1.1
Chloride (mg/l)	8.2	9.9	10.4	19.7	37.5*	1.9
Conductivity (micromhos)	221	235	243	284	363*	8.9
Total Kjeldahl Nitrogen (mg/l)	.22	.27	.28	.71	1.55*	.08
Total Phosphorus (mg/l)	.005	.012	.014	.032	.066*	.004
Chlorophyll <i>a</i> (ug/l)	7.6	7.6	5.0	37.5	99.1*	8.5
Total Solids (mg/l)	164	174	179	217	290*	15
Suspended Solids (mg/l)	1.6	2.7	3.2	8.1	17.6*	2.2

*These values are beyond the range of the sample data.

REMOTE SENSING UTILIZATION OF DEVELOPING COUNTRIES:AN APPROPRIATE TECHNOLOGY

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ABSTRACT

Studies sponsored by AID have verified that remote sensing technology can play a highly useful role in development. As a result, AID has committed itself to an expanded, multi-faceted program. This paper discusses AID's activities for establishing regional and national training and user assistance centers, conducting workshops and training seminars, conducting demonstration projects, carrying out research on applications, and granting financial and technical assistance to build or strengthen a country's capability.

I. INTRODUCTION

Two years before the launch of ERTS-1, AID recognized that remote sensing could have a substantial impact on development programs of developing countries. Accordingly, the office immediately initiated a program of analysis, cautious testing and experimentation designed to create an understanding of the role and impact of remote sensing in the developing process. This paper discusses the program that has evolved within AID from these early studies. For the purposes of this paper, AID's remote sensing activities have been grouped into the following six categories:

Training and Workshops
Research in Applications
Grants
Training and User Assistance Centers
LANDSAT in Projects
AIDSAT - High Level Awareness

It should be noted that these categories are not mutually exclusive. For example, people are trained in the process of working on projects, and grants are given to assist an investigator in carrying out research or project demonstrations.

Before discussing these elements of AID's remote sensing program, it may be well to say a few words about the appropriateness of remote sensing technology, and in particular LANDSAT, to development. LANDSAT is a product of a highly sophisticated technology, and the engineering required for its success is truly impressive. Consider for the moment just one parameter of the LANDSAT system —

repetitive coverage every 18 days. The linear velocity of a point on the equator due to the earth's rotation is 24,900 miles/day or 1,210 miles/hour or 20 miles/minute. If after 18 days or 252 orbits of the earth, the timing of the satellite crossing of the equator is off its nominal 0930 crossing by ± 1 minute, and the center point of two successive images of an area at the equator will be displaced from each other ± 20 miles. Yet the center point of LANDSAT images have remained within this displacement over several years of operation, a miracle in timing. Other parameters of the LANDSAT system have similar, high technology requirements.

Despite the fact that the LANDSAT system itself represents the cutting edge of technological development, extraction and use of information from LANDSAT data products can be done at almost any technological level. Useful information can be obtained from simple visual inspection with little or no training, e.g., black-and-white images can be used as a map substitute. With training and information extraction aids, such as a light table, color additive viewer, density slicer or zoom transfer scope, considerably more information can be extracted. For example, identification and mapping of surface features and land cover. With still higher technology such as computer processing, information from LANDSAT can be automatically extracted based on spectral signatures and changes occurring with time. Furthermore, the data can be presented as summary statistics or placed automatically in a geographic data base.

In large, underdeveloped areas where maps and resource information are inadequate for optimum project design, LANDSAT can provide various levels of information needed for assessing, monitoring, or extracting resources. As discussed in the preceding paragraph, the level of technology used to extract the information required by a country can be sized to its needs and/or abilities. It is AID's goal to assist developing countries to acquire the remote sensing capability appropriate to them. Figure 1 is a map of the world showing the developing countries which receive some form of economic assistance from AID.

II. TRAINING AND WORKSHOPS

The limiting factor in the transfer of technology is often the capability of the recipient country to absorb the technology. Capacity, in turn, is measured by the number of trained personnel available to receive and use the technology. Thus training is the common denominator in almost every project involving the transfer of technology undertaken by AID. Furthermore, training, because of its multiplier effects, is one of the best values for our AID dollars. Many foreign assistance programs only help the developing nations, but training helps them to be able to help themselves with far more lasting effects.

The importance of training in the transfer of remote sensing technology is no exception. Accordingly, training was one of the first activities undertaken when the Agency first became aware of the many important benefits of remote sensing technology for developing countries. In May 1973, AID sponsored its first international workshop in the Philippines. This workshop was of two weeks duration and covered the fundamentals of multispectral remote sensing from satellites. ERTS-1 imagery of the participants' own countries was used in lectures and laboratories and gave the workshop a sense of being directly applicable to development problems. Since that time, AID has sponsored similar workshops in Mali, Indonesia, Panama and Kenya and has participated with the U.S. Information Agency in regional remote sensing seminars. AID also sponsored the first two international training courses at the EROS Data Center. This course is now continuing on a twice yearly basis under U.S. Geological Survey sponsorship and has become the most widely attended international training course of its kind.

These training courses have not been one-way streets as far as the transfer of information is concerned. They have given AID valuable insights into the needs and capabilities of the countries they have served. Each course has been characterized by frank exchanges of views on the usefulness of this technology and its importance to application areas in the developing world. Each course has been concluded with a critique in which the views of the participants have been carefully analyzed and used in designing the next course.

REMOTE SENSING UTILIZATION BY DEVELOPING COUNTRIES: AN APPROPRIATE TECHNOLOGY

M. W. CONITZ AND D. S. LOWE

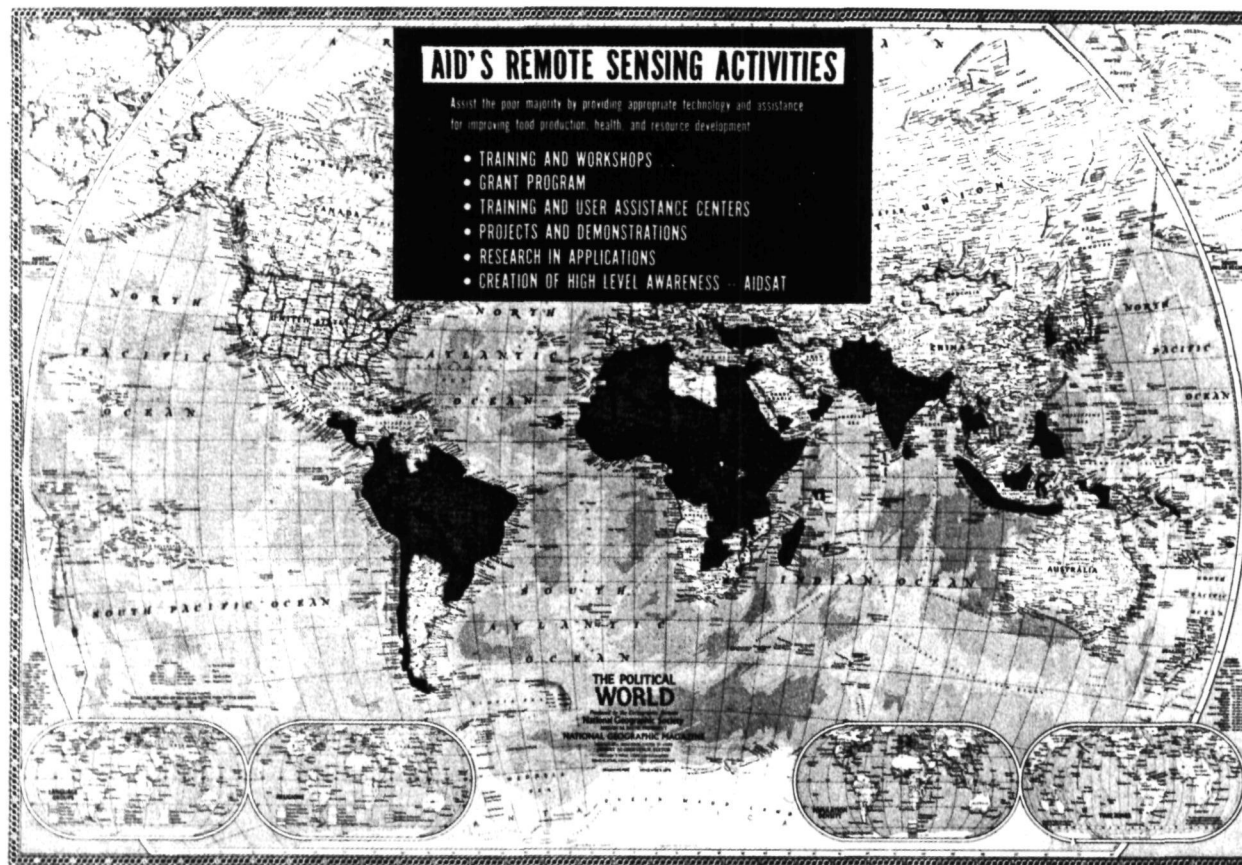


FIGURE 1. COUNTRIES WHICH RECEIVE ECONOMIC ASSISTANCE FROM AID

Two of the most significant conclusions have been the need for more intensive training to develop a higher level of competence in interpreting LANDSAT imagery and the need to make the training even more relevant for the participants. In response, AID has now designed a course with these objectives in mind. This course is presently being initiated in Nepal with the Remote Sensing Institute of South Dakota State University as the contractor. The course will begin with a seminar designed to familiarize the host country participants with the latest applications of the technology. The seminar will also familiarize the contractor team with the data needs of the host country, resource projects presently underway, and the key persons involved in resource management. If appropriate, three or four resource managers from the host country will be selected for further training in the U.S. under the guidance of the contractor. This training will extend for a period of four to eight months and will include the processing and analysis of imagery of previously identified project areas in the host country. After the trainees return to their home country, they will continue to work on these projects under the periodic supervision of the contractor. With the assistance of the contractor, they will provide workshops and on-the-job training for their colleagues. The total period of contact with the contract team will be approximately eighteen months.

It is hoped that this longer period of contact will be sufficient to establish the technology in the host country as a lasting institution. It is also hoped that permanent linkages will be developed between the host country managers and the U.S. scientists. Finally, it is expected that during this period, the trainees will have achieved a level of competence and confidence to enable them to continue on their own.

III. REMOTE SENSING GRANTS

A competitive grant program was instituted by AID in late 1974 to provide incentive to developing countries to achieve broader use of information available from LANDSAT and other types of remote sensing data. This program which is being administered by the Environmental Research Institute of Michigan is designed to strengthen the capability of in-country institutions, while they apply remote sensing technology to projects of high priority to the grantee's country. Each grant carries a financial award (nominally \$20,000) plus technical assistance in the form of training, acquisition of materials and supplies, and occasionally data processing at the request of the grantee. These grants are intended to support "seed projects" concerned with specific applications of remote sensing data. Each grantee designs and administers his own project and is responsible for its execution. Successful grant projects promote an increasing awareness of the value of remote sensing to economic development and a self-perpetuating and expanding use for remote sensing data within developing countries.

To date, ten grants have been awarded to investigators in ten different countries. Table I lists these grants by country and gives a brief description of the projects. Each investigator identified a project oriented towards a particular application area and national need. Each project had a specific set of data requirements and goals and was designed to take about one-year to accomplish, although unforeseen delays resulted in some projects lasting for longer periods. In selecting projects for support, emphasis was placed on the identification of a specific information need which could be met by use of remote sensing data, and which was important for development planning purposes.

The need for data from the U.S. earth observational satellites to perform the projects resulted in choosing investigators from countries that had NASA-approved LANDSAT experiments. In some cases, the AID grantee for a country was the same as the NASA principal investigator, in other cases, a different investigator was selected. In no case, however, was the AID grant project the same as the NASA-approved experiment. In some cases, the AID grant provided data and facilities complimentary to the NASA experiment, but each project was intended to be a separate and distinct effort. Three of the ten grantees are in South America, two are in Africa, and five are in South and Southeast Asia. These countries have a combined population of 318.8 million people and cover a total of approximately 2.84 million square miles.

TABLE I. AID GRANT PROJECTS

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<u>COUNTRY</u>	<u>GRANTEE</u>	<u>PROJECT</u>
South America:		
Bolivia	Dr. Carlos Brockman Servicio Geologico de Bolivia (GEOBOL), La Paz	Detect and identify iron ore deposits of economic significance in eastern Bolivia.
Chile	Messrs. German Errazuriz & Arnoldo Ortiz-Riveros Instituto de Investigacion de Recursos Naturales (CORFO), Santiago	Inventory the natural resources of Tarapaca and Antofagasta Provinces.
Peru	Mr. Walter Danjoy Arias Oficina Nacional de Evaluacion de Recursos Naturales (ONERN)	Identify and map the extent of the economically important Aguaji Palm in the eastern jungle.
Africa:		
Lesotho	Messrs. Anthony Jackson & Edwin M. Seithleko National University of Lesotho, Roma	Investigate snowfall, drainage patterns, and vegetation in relation to soil conservation requirements.
Zaire	Dr. Sendwe Ilunga, Director, ERTS-Zaire Bureau de President Kinshasa	Develop annotated LANDSAT images as cartographic substitutes by Institute Geographique du Zaire.
South Asia:		
Bangladesh	Prof. M. I. Chowdhury, Chairman, Department of Geography, Jahangirnagar University, Savar	Provide agricultural and land-use information for further develop- ment of the Haor areas in north- east Bangladesh
Pakistan	Dr. M. Shafi Ahmad, Director, SPARCENT - Pakistan Space & Upper Atmosphere Research Committee (SUPARCO) Karachi	Provide geomorphological information concerning vegetation and littoral conditions for construction of a new industrial port for the City of Karachi
Sri Lanka	Mr. Chris Nanayakkara, Survey Department, Ministry of Agriculture & Lands, Colombo	Develop digital analysis techniques for obtaining agricultural crop information.
Southeast Asia:		
Philippines	Mr. J. C. Fernandez, Director, Bur. of Mines, Department of Natural Resources, Manila	Provide natural resource information for integrated economic development of Island of Mindoro.
Thailand	Dr. Somnuk Striplung, Dept. of Agricultural Economics, Ministry of Agriculture & Crops Bangkok	Provide acreage statistics to annual crop surveys of corn, rice, and sugar cane.

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The specific objectives and results to date of the ten grants vary considerably. Four of the grant projects were primarily concerned with applications of remote sensing to agriculture (Bangladesh, Lesotho, Sri Lanka and Thailand), although the approaches were different for each. Two projects were concerned with multidisciplinary resources information needed for planning integrated development of underutilized regions (Chile and the Philippines), and one country each was concerned with cartography (Zaire), forestry (Peru), geology (Bolivia), and coastal zone development (Pakistan). This range of resource applications reflects the multidisciplinary nature of remote sensor-derived data and different information needs of different developing countries.

The grant financial awards were designated to be used for acquisition of data, supplies, equipment, training, travel and in several cases, some advanced data processing in support of the project. Funds were not to be used for salary or expenses incurred in connection with the investigator's normal duties. The time of the investigators and their colleagues were donated by their respective institutions, and facilities existing within the grant countries were expected to be made available as required.

In eight of the projects, the investigators were national government employees; in the two other cases, they were university faculty. Major emphasis was placed on supporting projects which seemed to have good linkages with decision-making institutions and involved a number of the agency or institution personnel at both the technical and administrative level. The capability of investigators to interact with various in-country institutions was a key consideration in selecting projects for funding. While the results of the grant projects are still being developed and documented, a preliminary evaluation indicates the occurrence of both successful and unsuccessful projects, with most projects being somewhere between these two extremes. Because of the low level of activity, several of the grants were judged as having limited success to date, but further progress may occur in time. As anticipated, the key ingredients leading to successful grant programs are (1) an energetic and enthusiastic principal investigator, (2) high level government interest and concern for the programs, and (3) involvement in an operational program of concern to the country.

IV. RESEARCH IN APPLICATIONS

In addition to training, technical assistance, and grant support for institutional development, AID supports research designed to explore those application areas which are of particular importance to developing countries. While much research has been undertaken in connection with the LANDSAT program, there are still many potential research areas that have been underexploited largely because they are of interest only to developing countries.

A typical example is in demographic applications. For the past three years, AID has sponsored demographic studies in Kenya and Bolivia. These projects are designed to determine whether census tracts of uniform population density can be identified on LANDSAT imagery based on observed land use. If so, reasonably accurate population estimates could be determined with relatively small samples. So far, the results of these projects have been very encouraging. This is an example of an application which would be of little interest in most developed countries because these countries already have the means to acquire much more accurate demographic data by conventional methods.

Another area where research is needed is in tropical agriculture. The LACIE program and other agricultural research has focused on temperate latitudes where large homogenous fields and regular seasons make the job of crop forecasting relatively easier. Some of these techniques may be applicable in the rice growing areas of Southeast Asia but much tropical agriculture takes place on small family size plots where a variety of crops is grown year around. To forecast crops and otherwise aid agricultural planners in these areas, we need to know more about what kinds of agricultural data are needed by the planners and how they can be collected. Such items as sensor types, resolution requirements and frequency of coverage need to be more clearly defined for use in tropical settings.

Desertification is another area where a great deal of research is needed. There is still insufficient evidence to state with authority the relative impact of human activity and weather changes in areas, such as the Sahel in West Africa, where desert encroachment is said to be taking place. One also needs to know more about rainfall characteristics and recurrent weather patterns in arid regions for more efficient land management. World-wide attention will be focused on these problems during the forthcoming United Nations Desertification Conference. AID is expected to join with other nations of the world at that time in seeking solutions to the problems of desertification.

Cartography is an application area where additional research could pay large dividends. Most developing countries are not only poorly mapped but they have inadequate geodetic control on which to base additional mapping. LANDSAT imagery has provided many of these countries with useful map substitutes. The next step is to determine the extent to which this imagery can be utilized in the production of medium and small scale photo-image maps with adequate geometric fidelity.

AID's development assistance program in remote sensing will, therefore, include a certain amount of pioneering in addition to the more routine training and technical assistance. The space program is still in its infancy, and as it grows, there will be even more opportunities for research in applications that directly benefit the developing countries. AID will continue to be watchful for these opportunities.

V. REMOTE SENSING CENTERS

The acceptance and use of remote sensing techniques can be facilitated by concentrating facilities and expertise into groups. For example, one can find user assistance centers in the United States which serve national, regional, or state needs rather than individual needs. For developing countries, which have limited human and financial resources, it is visualized that user assistance and training centers should be organized initially on regional and/or national levels. Such centers would provide data interpretation facilities, training and consultation on a readily available basis.

A center has a number of advantages for transferring remote sensing technology. For example, in the absence of a center, personnel are sent outside their country for training and too often find:

- (1) the training exercises address problems foreign to them,
- (2) their newly acquired enthusiasm is not shared or appreciated by their management,
- (3) they have no data or interpretation facilities,
- (4) their "foreign" training qualifies them for promotion to a different, non-remote sensing job.

The center concept not only provides data, facilities and consultation on a readily accessible basis, but its staff can conduct demonstration projects as well as an organized campaign to create awareness of remote sensing potential among high level government officials. Indeed, the existence of the center itself will be a stimulus for remote sensing activity.

Plans for establishing Regional Remote Sensing Training and User Assistance Centers at Ouagadougou, Upper Volta and Nairobi, Kenya have been approved. These centers are expected to be operational by the end of 1977. The Ouagadougou Center will service West Africa (the Sahel and bordering countries), and the Nairobi Center will service East Africa. It is anticipated that AID will establish additional regional centers in Asia and Latin America.

Each center will be staffed by four or five specialists representing different disciplines plus local technicians. Each center will also contain analytical equipment, imagery files, image reproduction facilities, a technical library and ground truth equipment. In addition to being able to provide workshops and other training, each center will have a strong outreach or extension

capability. The staff will be encouraged to acquire familiarity with the needs of the countries of the region in order to provide the kind of assistance that will directly satisfy those needs.

The regional centers will also be focal points for the development of networks and linkages. They will be important contact points between local resource managers and experts in the U.S. and elsewhere. The personnel of the centers will work closely with national universities in the introduction of remote sensing into their curricula. Remote sensing is seen as a tool in resource management just as mathematics is a tool in science or engineering, and AID's objective is to see remote sensing taught in the same way, that is, as an integral part of any resource oriented curriculum.

Care will be taken to select staff for the centers who are knowledgeable about developing country problems and who will not oversell the technology or stimulate expectations that cannot be fulfilled. In fact, the stated goal of AID's assistance program in remote sensing is "to assist developing countries in improving their capabilities for assessing and managing resources through the use of remote sensing and other appropriate technologies." As much of the training and technical assistance as possible will be undertaken in the recipient countries working with ongoing projects of high national priority. Skilled resource specialists are in short supply in most developing countries and cannot be diverted for long periods of training away from home or on projects that are merely designed to demonstrate new techniques. AID will, therefore, seek opportunities to work directly with resource managers on existing projects and demonstrate how various remote sensing techniques can improve the efficiency of resource data collection.

It is expected that nations will want to have their own centers as their remote sensing requirements expand. One should not look upon national centers as competitors of the regional centers. Rather, they compliment one another. In general, regional centers will be a larger and more sophisticated operation than the national centers as the former serves a larger clientele and can draw upon a larger body of technical expertise for its staffing. Thus, the regional center could provide more sophisticated analysis or processing than would be possible at the country level.

Recognizing the importance of a well directed national remote sensing program, AID is also sponsoring the development and strengthening of national remote sensing centers. A program of this nature has already been approved for Zaire. This program is focused on building and strengthening ties between the ERTS-Zaire program office and user organizations.

VI. AIDSAT — CREATION OF HIGH-LEVEL AWARENESS

Since remote sensing is a tool to service multiple users, development of the technology requires at least multiple agency cooperation, if not, organized multiple-agency support. These requirements impose a need for high level management awareness and support for remote sensing. Taking advantage of the fact that NASA was moving the ATS-6 geostationary communication satellite and the U.S. bicentennial celebration, AID contracted NASA to conduct a demonstration to make heads of states and their staff aware of how the space age technologies of communication and remote sensing can help developing countries. This program reached 27 countries in the fall of 1976. It created high-level government awareness of remote sensing applications and more importantly committed AID to the development of a program of sharing these technologies with the poorer countries of the world. This commitment had earlier been voiced by the Secretary of State who said at the United Nations Conference on Trade and Development in Nairobi, "Satellite technology offers enormous promise as an instrument for development. Remote sensing satellites can be applied to survey resources, forecast crops and monitor land use. AID is prepared to cooperate with developing countries in establishing centers, training personnel, and where possible, adapting our civilian satellite program to their needs."

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The AIDSAT program warrants discussion far beyond the scope of this paper. For the reader unfamiliar with AIDSAT, a brief description follows. The ATS-6 is an experimental, high-powered, geostationary communication satellite. Broad-band video data can be transmitted and received with antennas only 10 feet in diameter. The parking station for the geostationary satellite was being moved from over the Indian Ocean to the Pacific Ocean. As the satellite made its three-month westward journey, live color television programs were beamed between the U.S. and each of 27 countries in Asia, Africa, and South America. One portable receive and transmit terminal was set-up in the capital city of the developing country and up to three receive-only terminals were set-up in outlying cities. The audiences in the capital cities consisted of about 150 high-level government officials and often included the chief-of-state. The U.S. beamed a filmed greeting from President Ford and three excellent color films, one of which described LANDSAT and its applications. This was followed by a live, two-way panel discussion between officials of the host country and a panel of experts in the U.S. The panel moderator was an astronaut who selected the U.S. respondee to questions or comments posed by the host country panel. These questions were stimulated by the films being shown. Much of the time and interest of the live, one-half hour panel discussion was directed toward how LANDSAT could assist the host country in working out specific problems associated with their development.

VII. LANDSAT APPLICATIONS IN AID PROJECTS

Despite the fact that the LANDSAT program continues to carry the experimental label, the imagery produced has many useful applications in operational projects. This is especially true in developing countries where LANDSAT imagery is often the most up-to-date and reliable source of data. Accordingly, AID has begun using LANDSAT imagery routinely in resource investigations.

One of AID's first experiences in using LANDSAT imagery as an operational tool was in a range study in Tanzania recently completed by the Earth Satellite Corporation. In this project, covering the Masai region in northern Tanzania, LANDSAT imagery, supported by aerial and ground observations, was used as the basis for determining the possibilities and limits in land use for agricultural cropping and range and water resource development. LANDSAT imagery was used to help identify vegetation cover, land use, soil associations, and fracture zones that might be indicators of ground water.

In West Africa, LANDSAT imagery has been used in a similar manner in Mali to provide the basic data source for a comprehensive resource inventory. Here again, LANDSAT imagery is being used to map vegetation, soils, land use, and other elements needed to provide planners with a source of information for decision making.

Through the use of this technology, AID hopes to assist development planners to avoid some of the mistakes in land utilization that have led to overgrazing, deforestation, and soil erosion. AID, in cooperation with the African Development Bank, is planning to support a major land suitability study and resettlement plan for a large area in West Africa that is being freed from the threat on onchocerciasis or river blindness. Recent control measures have been effective in freeing areas in Ghana, Benin, and Upper Volta from this disease but the countries correctly want to develop orderly, rather than random, plans before permitting resettlement of these areas. The techniques employed here could also be used in other resettlement schemes, such as the tsetse fly infested areas of East and Central Africa when those areas are made inhabitable.

VIII. SUMMARY OF AID'S REMOTE SENSING PROGRAM

Since the launch of ERTS-1 in July 1972, AID has been involved in fostering the use of satellite data for developing purposes. This involvement began with cautious experimentation and training in the fundamentals of image analysis. The studies conducted by ERIM [1] and the National Academy of Sciences [2] have given the Agency additional assurance of the usefulness of this technology and guidance on future assistance efforts. This has led to the distribution of grants to support local initiatives and institutional development and the use

of the imagery in an operational mode on various resource inventory projects. With positive feedback from these activities, the Agency publicly committed itself to a greatly expanded level of assistance in remote sensing for developing countries during the AIDSAT demonstration. As a result of these commitments, requests have been received from numerous countries throughout the world. Examples are requests for assistance in the development of national laboratories in Zaire, Tunisia, and Thailand; training programs in Nepal, Tanzania and Sudan, and several Central American countries; resource inventories in the Central African Empire, Cameroon and others; and various miscellaneous projects, such as monitoring deforestation and soil erosion. The response to these requests will include further development of institutional capability in the form of regional centers to give the developing country resource managers more direct access to sources of assistance.

As long as AID remains committed to such humanitarian goals as alleviating hunger throughout the developing world, the Agency will seek to utilize new and appropriate technologies, such as remote sensing, which promise to help overcome the slow evolutionary pace of development.

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OMIT

IMPACT OF ENVIRONMENTAL INFORMATION FROM LANDSAT TO
PETROLEUM EXPLORATION IN THE GULF OF ALASKA

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SUMMARY

The application of Landsat data has had a significant impact upon the exploration activities in the northern Gulf of Alaska. The existence of a persistent circulation pattern west of Kayak Island was recognized on Landsat imagery and later confirmed by oceanographic studies. The implications of the gyre condition were so pronounced that the Secretary of Interior deleted sixteen tracts for a major oil lease sale just five days prior to the sale. It was judged that the risk was too great for environmental damage to marine life in the offshore drilling area and along the shore where any contaminants would be carried by the gyre rather than to disperse at sea.

A map of cover types prepared along the Yakutat Forelands from computer-aided analysis of digital Landsat data also became a valuable tool for planning onshore activities in support of the offshore exploration. The Landsat results yielded clues to the region's natural processes because the vegetative types and stages of succession in this region are very closely related to the geologic and hydrologic factors which continue to shape the environment. Old beach lines and sediment trajectories evident in the satellite data confirmed the source and mechanism for the beach-building process that occurs along most of the forelands. Vegetational clues also give evidence of a history of catastrophic hydrologic events along the forelands. Apparently many hundreds of years ago the overflow from the glaciers feeding Russell Fiord drained across the forelands because numerous old channels are engraved in the data as mature spruce (climax species) against a background of mixed forest. A similar, but obviously more violent and probably more recent event occurred as an outburst flood from Harlequin Lake. Instead of old, meandering channels as from Russell Fiord, the outburst from Harlequin Lake carved striations indicative of a sudden, massive release of water. Maps of vegetative cover types prepared from digital analysis of Landsat data show two reasons to postulate the Harlequin Lake event occurred more recently than the overflow from Russell Fiord. The old flow channels from Harlequin Lake appear as seral stages of vegetation carved into the background of remnant stands of mature spruce; also, the straighter channels from Harlequin Lake cut across some of the overflow channels from Russell Fiord. Both of these features tend to date the Harlequin Lake event as the more recent relative to Russell Fiord.

A final environmental tale was derived from the classification map. A stand of mature spruce apparently acts as a climatic buffer along the beach line of the western forelands. At Situk Bay the conifers have been stripped away, possibly by the events associated with Russell Fiord or Harlequin Lake or by more recent storms. Here the unbuffered winds are drifting the exposed sand landward causing the retreat of the vegetation in this region. A similar type of severe stress is also apparent along the southern beaches of Ocean Cape and Kahntaak Island, where the intermediate stages of succession are no longer conspicuous between the ocean and the inland stands of climax species.

This study helped to define the sensitive aspects of the environment of the forelands. It confirmed that much of the region is not suited for industrial development owing to the potential hazards of life and property from outburst flooding, as well as likely adverse effects from erosion should the pattern of stands of tall coastal forests be broken for development purposes. As a consequence onshore facilities are being concentrated at Yakutat Harbor and at Dry Bay rather than the sensitive region of the forelands.

A SURVEY OF USERS OF
EARTH RESOURCES REMOTE SENSING DATA

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ABSTRACT

Uncertainties exist as to the extent that LANDSAT and related remote sensing data are currently being utilized. This paper summarizes the results of a NASA supported Battelle survey⁽¹⁾ to obtain user views on the nature and value of LANDSAT data use, on current LANDSAT capabilities, and on ways to improve data use. Questionnaire and interview responses from over 1000 private and public sector users are analyzed and discussed. Survey results should help both NASA and data users develop even more beneficial satellite data applications programs.

1. INTRODUCTION

In response to a request by the Space Applications Board of the Assembly of Engineering (National Research Council of the Academy of Sciences), the Director of NASA User Affairs - Office of Applications funded Battelle's Columbus Laboratories to undertake a survey to clarify and document the application and effectiveness of the use of Earth resources survey (ERS) data by the user community.

The scope of the study was limited in "data used" to only high-altitude aircraft (>60,000 ft: RB 57 and U-2 type aircraft) and satellite (primarily LANDSAT) data; but, in terms of "data user", the scope was to be comprehensive and include all data user communities (i.e., industry, government, educational, and non-U.S. or foreign users). The study was not a market survey to identify new markets but rather a user survey to determine current ERS data use/user status and recommendations for strengthening use.

2. SURVEY METHODOLOGY

The Earth resources data use survey basically involved a two-phased research procedure, see Figure 1. The first phase focused on identifying, obtaining, and reviewing information from such direct sources as (1) the three ERS data centers (EROS Data Center, Sioux Falls, South Dakota; USDA Data Center in Salt Lake City, Utah; and, the NOAA Satellite Data Services Branch in Suitland, Maryland), (2) structured and unstructured personal and telephone interviews, (3) tailored and comprehensive questionnaire surveys and (4) selected ERS user presentations/publications. The second phase of the survey involved the aggregation and analysis of the information and data according to the following user groups: (1) industrial users, (2) state, regional (substate) and local government users, (3) federal government users, (4) academic/educational users, and (5) non-U.S./foreign users. Within each user group an effort was made to determine who are the current users, how they are using the ERS data, what is the current significance of their ERS data use, and lastly, how can ERS data use be strengthened. An ERS data use summary and outlook assessment for each user community as well as for the total study were prepared using all direct and indirect information sources. This paper only summarizes the survey data base and some of the major survey findings. The detailed results are contained in the final research report available through NTIS.⁽¹⁾

3. SURVEYS CONDUCTED

During this study three separate, but structurally related, surveys were conducted: (1) Houston ERS Symposium survey, (2) user interviews, and (3) mail survey. Figure 2 provides an overview of the statistics for all surveys conducted by user group. With the exception of

non-U.S. data users, a fairly uniform distribution of responses within each user category resulted from the total 1161 users contacted.

3.1 Houston ERS Symposium Survey (All Participants)

Because of the coincidence of the timing of this study with the first comprehensive symposium on the practical application of Earth resources survey data (held by NASA in Houston, Texas in June 1975), it was considered opportune to conduct a questionnaire survey of all conference attendees. Hence, a simple one-page (both sides), primarily multiple-choice questionnaire, developed in concert with NASA, the Space Applications Board, and the Office of Management and Budget, was included in the ERS Symposium packet distributed to all participants. Of the 1337 registered participants, 373 (or ~ 28 percent) completed and returned the questionnaires. The user community distribution, for those questionnaires returned, is shown in Figure 2.

3.2 User Interviews

Much of the effort expended during this survey activity related to conducting telephone and personal interviews with the more frequent/experienced ERS data users. Approximately 400 user interviews were conducted between July 1975 and March 1976. The distribution among user groups was as shown in Figure 2. Information obtained from interviews was considered to be of higher information value than that contained in questionnaire responses, and accordingly had more impact on conclusions drawn and recommendations made in the final report.⁽¹⁾

3.3 Mail Questionnaire Survey

In this broader survey, questionnaires were mailed to attendees of recent remote sensing symposia, LANDSAT I and II investigators, members of professional remote sensing societies, individuals identified from NASA Headquarters, JSC, and GSFC mailing lists, and others from ERS data center information. Individuals who returned questionnaires from the Houston ERS symposium and non-U.S. users were not included in the mail survey. In brief, some 1200 questionnaires were mailed and 389 were returned for a 32.5 percent response rate, which is quite acceptable for a mail survey. In this mail survey, lower priority was given to the educational community, but returns from other user groups were fairly evenly distributed, as seen in Figure 2.

4. SUMMARY OF SURVEY RESULTS

One factual representation of the extent of current ERS data use can be obtained by aggregating the business statistics from the three operational ERS data centers in the United States. Figure 3 depicts these statistics, which indicate a fairly substantial annual dollar volume increase since FY 1973, and projected through FY 1976 (a total volume of over 3 million dollars). These figures indicate that the purchase of both LANDSAT frames and tapes continues to increase. For FY 1976, it was estimated that 280,000 LANDSAT frames and 2250 magnetic tapes would be purchased. This would make a total of over 700,000 LANDSAT frames sold since FY 1973.⁽²⁾

4.1 Data Users

Figure 4 shows the overall survey results in terms of Earth resources survey data users and data applications. The survey indicated the existence of a substantial number of current ERS data users. During this survey alone, over 1000 users of several thousands estimated were contributors. Lists of principal data users in the industrial, governmental, and academic communities have been included in the final report.⁽¹⁾ Based on federal data center LANDSAT sales (FY 73-FY 75) of slightly over \$2 million and 500,000 LANDSAT frames, industrial (private sector) users are the largest single user group (in terms of both dollars and items), followed very closely by non-U.S./foreign data users. Federal governmental agencies and academic/educational users are about equal, but considerably less than users from the industrial sector. Very small in relative comparison is the apparent degree to which state, regional (substate) and local governmental units are purchasing LANDSAT data.

4.2 Data Used

Types of ERS data currently being used are also indicated in Figure 4. Survey results indicate that more users are involved with LANDSAT imagery than with any other type of ERS data. The use of high-altitude aircraft data follows a close second. LANDSAT digital data and Skylab

data were being used in about the same relative proportion (that is, by little less than 50 percent of users surveyed).

4.3 Data Use/Utility

As shown in Figure 5, current data applications among the various disciplines are fairly uniform with the exception of the peaks occurring in land use and geological applications. Actually, geologically related applications by the private sector account for the largest single data use category. Estimates are that industrial use of ERS data for mineral and fossil fuel exploration may be 10 times greater than other current applications. Other industrial applications include: land use/land cover studies; agricultural, forestry and other resource inventories; and facility siting assessments. Federal governmental agencies are actively pursuing all application disciplines, with the most substantial effort occurring in land use, agricultural, water/marine resource and geological applications. Because of the availability of funds and expertise, this user group represents the key to the effective transfer of ERS technologies to other governmental user communities. State, regional (substate) and local governmental users have been slow in developing operational ERS data programs, primarily because of a combination of funding and capability limitations, inadequate spatial resolution of LANDSAT imagery, and institutional arrangements and policies which adversely affect the technology transfer process. To date, the most progress made by this user group has been land use/land cover inventorying and mapping applications. Academic users are providing some of the leadership in developing techniques for using ERS data. Often the academic user is the means whereby geographically associated governmental and private organizations are being made aware of the application potential of ERS data. Foreign users are currently involved at all stages of data use from specialized, problem-solving experiments (such as general range condition monitoring in Lesotho, South Africa) to completely operational programs (viz., sea ice monitoring in Canada). U.S. training and user assistance programs, private industry involvement, and international support (UNDP and World Bank) are contributing factors to the growing impact of ERS data on developing countries.

As shown in Figure 5, most questionnaire responses indicated LANDSAT-type data to be of high utility. Most users surveyed consider current ERS data and data products to represent a complementary data source which has the potential of becoming an important data source. Most users feel that current ERS data products are of the greatest benefit to them because they represent a unique/new data source and a cheaper data source. Also, most users believe that ERS data systems have the potential of providing better data for most application areas. User assessments by discipline show that current ERS data products are most relevant to geological applications, land use activities and water resources interests. Most users feel that ERS data products will eventually be of most value to land use, agriculture/forestry, and water resources. Future ERS data were also considered to have high potential for providing unique data for environmental needs.

4.4 Data Limitations/Recommendations

Although questionnaire responses from all user communities showed strong agreement that most current LANDSAT data capabilities could be considered as adequate, with the exception of data delivery (see Figure 6), interviews with representative ERS data users did not substantiate this assessment. A more accurate representation of current user views relative to the adequacy of current LANDSAT capabilities and corresponding user recommendations for improving LANDSAT data use are summarized in Table I. Strongest user concerns related to the need to improve data delivery and spatial resolution. Lesser concerns related to the width and coverage of spectral bands and frequency of repetitive coverage. User recommendations having the highest overall potential for strengthening current LANDSAT data use included improving data quality on user products, providing more high-altitude aerial photography to be used in concert with LANDSAT data, and providing more user assistance/training programs. For improving data utilization of future LANDSAT-type systems, the greatest user impacts would result from significant improvement in data delivery (including a quick-look capability), more extensive spectral coverage, higher spatial resolution, development of specialized satellites, and acquisition of user data on an "as-needed" basis.

5. DATA USER PROFILES

5.1 Industry Users

Private industry is currently the most prominent user of LANDSAT data, buying a fourth of all LANDSAT data sold by the data centers annually, at a cost of \$483,000. Private industry

consists essentially of two types of LANDSAT data users: the industrial end user, who requires the data to locate new or monitor existing natural resources, and the industrial service-to-user who provides the end user (private, government, foreign) with hardware, software and/or services for the accomplishment of his mission. Among the private end users, the exploration industry for minerals and fossil fuels has used the data most successfully. All other end users have used the data less successfully. The use of LANDSAT data in the service-to-user industry is also routine; however, the resulting products are not always routinely used by the recipient. An evaluation of LANDSAT data by the industrial sector revealed that most industrial users want additional spectral coverage in the thermal infrared bands (1-2 μm), better spectral and spatial resolution (at least 2X), more foreign and remote area coverage, quick-look capability, stereo coverage, better data processing, and (above all) much faster delivery of data (days instead of weeks). Since a large part of the industrial sector is made up of exploration end users or image-processing service-to-users, the demand by the industry user for LANDSAT data in its present format is expected to decline, unless improved or new data formats or new data become available.

5.2 State, Regional (Substate) and Local Government Users

Use of LANDSAT data on the state and local level was assessed to be in one of three stages of development: (1) planned/potential - 10 states; (2) experimental - 23 states; (3) demonstrational/quasi-operational - 17 states. No state was found to use LANDSAT data on a routine operational basis, but some states, such as Alaska, were found to place much importance on the value of ERS data. State and local users purchase only 1 percent of all LANDSAT data, but are frequently aided in research and funds by federal agencies, and in research by private and university remote sensing technologists. State-level utilization of LANDSAT data is most impeded by: (1) insufficient time for technology transfer of a highly complex technology, (2) political processes wherein decision-makers and R&D priorities are frequently changed, (3) the spatial resolution of LANDSAT data, and (4) lack of commitment to an operational satellite system. Of this, the spatial resolution of the data appears to be the most critical factor. Many state users were attracted from the beginning to the unique perspective provided by LANDSAT multispectral coverage, but were disappointed by the lack of detail when trying to determine detail at their conventional 1:24,000 scale. Acceptance of LANDSAT data by state and local users will involve a long process in which federal support (in terms of funding incentives and technological leadership) will continue to play a dominant role. Preference for NASA data will be for high-flight data; LANDSAT data will be used primarily for regional inventory and mapping. The planned introduction of 30 to 40-meter resolutions of future ERS satellite data systems will hasten the acceptance of ERS data, but until state users employ digital processing techniques, such data will remain underused.

5.3 Federal Government Users

Federal government ERS data efforts, to date, have been piecemeal, experimental, investigative, or continuing demonstrational efforts, and many federal agencies have taken a "wait and see" attitude and have made no real commitment to develop the technology. In terms of EROS data sales, federal users represent the third most prominent data user group. Most advanced governmental satellite data users involve agencies within the Departments of Agriculture, Defense, Interior, and Commerce. These agencies routinely utilize high-altitude aerial photography and are attempting to use LANDSAT data in their day-to-day operations. These agencies are committing significant staff and funds to cooperate with NASA in developing methodologies and procedures for operationally using data from current ERS satellites. This user group has the necessary budgets, facilities, and remote sensing expertise to develop and implement operational programs. These federal agencies represent the key to ERS data technological transfer and development, and progress in the use of this technology, not only within the federal sector but also as it relates to the transfer and acceptance by other user groups. Increased spatial resolutions, added spectral coverage, and improved data handling capabilities in the LANDSAT follow-on programs will significantly expand data use within federal agencies. In the meanwhile, user groups will continue to demand better resolution data on or more timely basis as they attempt to operationally utilize LANDSAT-type data.

5.4 Academic/Educational Users

The academic user community has been primarily instrumental in developing techniques and providing assistance to other user groups for using ERS data. Educational institutions purchase 15 percent of all LANDSAT data at an approximate cost of \$100,000 annually. While academic users are primarily research-oriented, they also use ERS data for educational

purposes. Probably no other user community has utilized LANDSAT data for so many applications, the most frequent investigations being for land use and agriculture applications. Academic users are heavy users of digital data but have also used a variety of conventional photointerpretation techniques. Academic users in general consider most LANDSAT data parameters as "adequate", except for data delivery time. This user group will continue to utilize ERS data in research and educational programs, but probably not to the extent displayed in the past.

5.5 Non-U.S./Foreign Users

Non-U.S. users of ERS data currently represent a large user community which has the potential to become the predominant single user group in the near future. Foreign use of ERS data centers and the establishment of independent ground stations are steadily expanding. Major benefit is in areas where maps are inadequate and/or unavailable as required for resource development and economic programs. Current data capabilities are finding extensive use, but improved capabilities involving more and better foreign area coverage and data delivery will produce more extensive uses and benefits.

6. MAJOR CONCLUSIONS

An Extensive and Increasing Number of Explicit and Identifiable Data Users Do Exist. They include (1) users purchasing and analyzing ERS data routinely using their own resources (selected private industry and most foreign-country users), (2) users developing and testing systems for routinely using ERS data for large-area, small-scale resource inventorying, monitoring, and modeling applications, and (3) users analyzing the data experimentally to evaluate the feasibility of additional applications.

The Extent of ERS Data Center Use Varies Significantly Among the User Communities. The primary current ERS data user group is private industry, with both end-users and service-to-users participating (major use within the private sector relates to mineral and petroleum exploration interests). The second largest user community of ERS data is non-U.S./foreign users. Federal governmental agencies and the academic community are roughly tied for third place in extent of ERS data use, which involves all application interests. In last place are state, regional (substate) and local users, who appear to be more involved than data center records indicate.

Relative Discipline Use of ERS Data is Fairly Uniform. Although land use and geological applications appear to represent the largest current discipline application interests, overall data use is fairly uniform. The exception is environmental use which has considerably less current user interest than the other disciplines.

ERS Data Utility Varies Among Users and Uses. Most mineral and oil companies are of the opinion that current data use varies from important to very important in both domestic, and especially in foreign exploration, decision-making activities. In contrast, most other users, although positive, were not as strong or consistent in their views as to the effectiveness and value of current ERS data products. User assessments by discipline show that land use and geology applications are the most relevant current uses of ERS data, but land use, agriculture/forestry and environmental applications are expected to increase in importance with time. In terms of overall benefits, users believe that land use and water resources areas will benefit the most from ERS-type data.

Significant Increase in ERS Data Users, Uses, and Value Will Result From Planned and Possible Improvements in Future LANDSAT System Capabilities. Extensive progress has been made in (1) linking users and user problems with ERS data capabilities, (2) identifying and conducting experiments to assess technical and economic application possibilities, (3) developing demonstration/quasi-operational systems (LANDSAT II and ASVT programs) for using the data routinely, and (4) identifying and developing improvements to upgrade operational uses of future systems. Planned, short-term improvements (e.g., LANDSAT C) will result in some use/user increase, but more extensive improvements in data acquisition, data processing (on-ground and on-board), data delivery and end-user experience and capabilities will be required before extensive, user-financed, ERS data use occurs on an operational basis.

7. MAJOR RECOMMENDATIONS

Based upon information collected and evaluated during this survey, the following recommendations were offered:

- (1) NASA should accelerate plans and programs to develop satellite ERS systems capable of providing improved data which can be more effectively utilized (technically and economically) by a larger cross section of private and governmental end users.
- (2) NASA should develop and implement specialized technology transfer scenarios/ plans to improve ERS data utilization within each user community and within each discipline area. Establishment of regional application training centers and specialized user workshops should receive high priority.
- (3) NASA should make more information available to existing and potential satellite data users that will make them more cognizant of space plans, capabilities, and specific data participation opportunities. In remote sensing applications; the following information aids are very much in demand:
 - More newsletters of the GSFC LANDSAT NEWSLETTER type
 - A users' guide to availability of remote sensing data (high-altitude aircraft data as well as satellite data)
 - A users' dictionary of remote sensing terms
 - A users' guide to hardware/software for ERS data analysis
 - A users' guide to remote sensing research and service industries and contractors
 - A users' information hot-line so users can contact NASA relative to data applications inquiries
 - User handbooks for individual ERS data application areas.
- (4) NASA should take another hard look at the technical, cost, and application implications of developing specialized satellites (e.g., ice monitoring/ navigation, geological exploration, environmental monitoring, etc.), especially in view of upcoming Shuttle and Spacelab opportunities.
- (5) NASA should review on-going technology development programs and plans relative to their significance to future ERS systems and ERS data use. Programs having the highest potential for significantly improving ERS data use relative to user requirements should be discerned, and a determination made of the implications of accelerating their completion.

8. ACKNOWLEDGEMENTS

This research was supported by NASA User Affairs - Office of Applications. The authors wish to take this opportunity to thank the numerous contributors for their interests and their time in completing the survey questionnaires and/or participating in the personal interviews. Also, the assistance of the numerous Data Centers and NASA personnel, in particular, Mr. Dan Richard, Jr. of the NASA Office of Applications, is gratefully acknowledged.

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INFORMATION COLLECTION AND ANALYSIS		RESULTS, ANALYSIS AND IMPLICATIONS ASSESSMENT
DIRECT SOURCES (STUDY GENERATED)	INDIRECT SOURCES (OTHER)	▲ AGGREGATION OF RESULTS RE ● EPS DATA USER STATUS ● ERS DATA USE STATUS ● ERS DATA USE EFFECTIVENESS ● RECOMMENDATIONS FOR STRENGTHENING USE ▲ SUMMARY AND IMPLICATIONS OF RESULTS (PER EACH USER GROUP) ▲ TOTAL STUDY SUMMARY AND RECOMMENDATIONS
● DATA CENTERS ● USER INTERVIEWS ● QUESTIONNAIRE SURVEYS ● USER PRESENTATIONS AND PUBLICATIONS	● OTHER SURVEYS ● NASA PERSONNEL ● NASA AND NASA CONTRACTOR REPORTS ● ERS CONFERENCES ● SELECTED LITERATURE ● SPECIAL STUDIES	

FIGURE 1. SURVEY METHODOLOGY - OVERVIEW

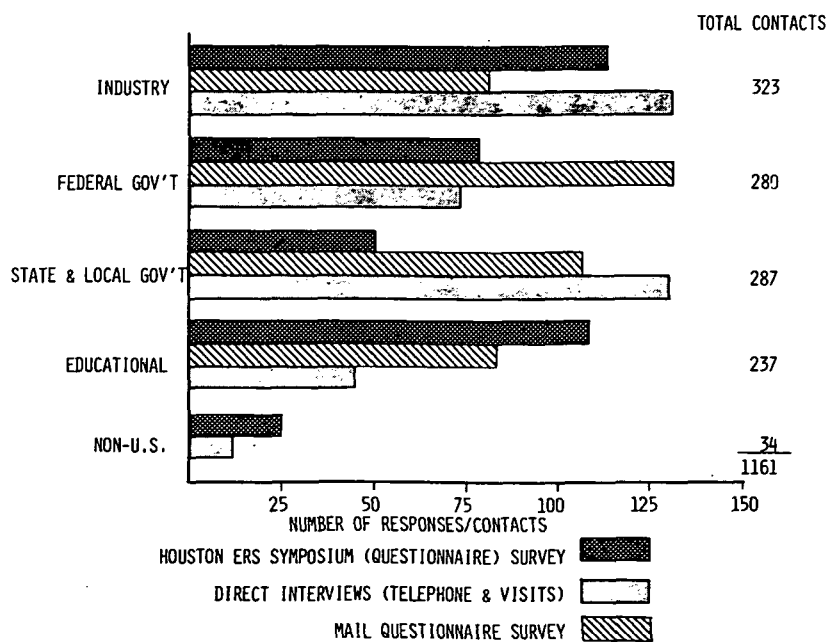
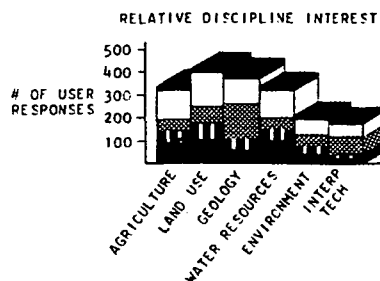


FIGURE 2. TOTAL USER SURVEY STATISTICS

DATA USE

DISCIPLINE/APPLICATION INTEREST

- FAIRLY UNIFORM LANDSAT DATA DISCIPLINE USES
- GEOLOGY/MINERAL APPLICATIONS AND LAND USE STRONGEST DATA USE AREAS
- AGRICULTURE/FORESTRY AND WATER/MARINE RESOURCE SECOND
- ENVIRONMENTAL APPLICATIONS SMALLEST CURRENT USE CATEGORY
- INDUSTRY GEOLOGY/MINERAL DATA USE LARGEST SINGLE DATA USE CATEGORY



UTILITY ASSESSMENT

- LARGEST NUMBER OF USERS CONSIDER ERS DATA TO BE OF HIGH UTILITY
- UTILITY VIEW FAIRLY UNIFORM AMONG ALL USERS
- INADEQUATE SAMPLE EXISTS FOR FOREIGN USERS

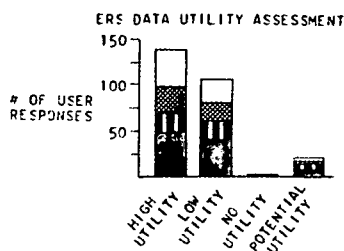
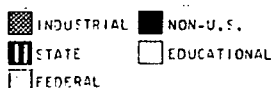
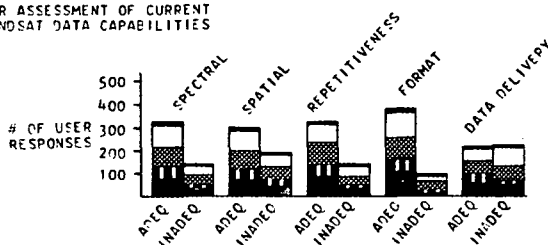


FIGURE 5. SUMMARY ERS DATA USE/UTILITY (ALL USERS)

USER ASSESSMENT OF CURRENT LANDSAT DATA CAPABILITIES



USERS STRONG AND UNITED ON DATA DELIVERY INADEQUACY-
THINK SPATIAL AND SPECTRAL CAPABILITIES SHOULD ALSO
BE IMPROVED- MOST OTHER CAPABILITIES CONSIDERED
ADEQUATE

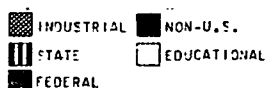


FIGURE 6. SUMMARY OF USERS' ASSESSMENT OF LANDSAT DATA (ALL USERS)

TABLE I. USER ASSESSMENT OF CURRENT LANDSAT DATA CAPABILITIES
AND RECOMMENDATIONS FOR STRENGTHENING DATA USE

USER VIEWS	USER RECOMMENDATIONS
• <u>Spectral Coverage</u> - Majority of users satisfied but many strong views as to limitations. • <u>Spatial Resolution</u> - Majority of questionnaire responses indicated current spatial capabilities adequate for experimental and large area uses. User interviews (with exception of exploration users), however, showed strong views as to data utility limitations imposed by 80 meter resolution. • <u>Repetitive Coverage</u> - Most users content with current LANDSAT data coverage except those concerned with environmental monitoring, snow mapping, flood drainage assessment programs, etc. and areas with extensive cloud cover. • <u>Format Options/Product Quality</u> - Strong user agreement on adequacy of current data quality. • <u>Data Delivery</u> - Strongest area of user dissatisfaction in both questionnaire and interview results especially in considerations involving operational use.	• Most recommendations are for (1) extending spectral coverage into thermal and microwave regions, (2) providing additional visible and near IR bands, and (3) narrowing existing bands. • Most users commonly recommended 20-40 and 10-20 meter resolutions. Some users (especially state and local users) desire spatial resolutions in the 1-10 meter range. In contrast, geologists want to retain large area (synoptic) perspective. • Strong recommendations related to other than repetitive coverage. Industry (and foreign users) in particular want more coverage of remote domestic and foreign areas and stereo viewing opportunities. • Most recommendations relate to providing more product options and better quality control. • User recommendations were many and very strong on need to significantly improve this function. Desires for quick-look capability and 2-3 days turn around time were stressed.

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THE SUYUZ-22 MISSION - PART OF A COMPLEX INVESTIGATION
OF EARTH RESOURCES IN USSR AND GDR

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ABSTRACT

As a joint INTERCOSMOS project a six-channel multi-spectral camera MKF-6 was developed by scientists of USSR and GDR, manufactured by Carl-Zeiss Jena (GDR). A short description of its most important elements is given. During the operation of the camera on board the spacecraft SUYUZ-22 over selected regions of the two countries were also taken pictures of the same areas and nearly at the same time by another MKF-6, installed on board an aircraft. Furthermore, the state of these "test" regions were studied by different ground based measurements and by a general mapping of the surface.

The aim of such a 3-level investigation is explained. Some examples of MKF-6 images will be shown and used to illustrate the function of a special color mixing equipment.

3017

DATA PROCESSING FOR NASA'S FIRST
SPACE BASED SYNTHETIC APERTURE RADAR

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SUMMARY

In May 1978 NASA plans to orbit its first space based Synthetic Aperture Radar. This initial effort is a "Proof of Concept" experiment, and the data from this system is expected to be carefully evaluated by interested users.

The presentation will review the end to end system design from satellite collection of data through processed and analyzed images. Included will be a detailed description of the following system elements.

The satellite system consisting of:

- o A 13m x 2.5m planar array antenna subsystem
- o The L Band Radar Design
- o A 20 MHZ Analog Transmitter to downlink the complete phase history to ground receiving stations.

The Ground Receiving Stations Highlighting:

- o Station Coverage
- o Special Receivers at each Station
- o High Data Rate Recorders 120 Mbps being developed for this application.

The Planned Ground Data Processing System Required to:

- o Convert Phase History Data into Image Data
- o Provide data records compatible with the EROS Data Center to enhance general user distribution of all image data products.

Data Analysis Plans & System Experiments Including:

- o Specific ground truth validation experiments for ocean, ice, coastal zone, and land data evaluations.
- o Post image processing for image enhancement and analysis of wave spectra, ice histories, contrast discriminations, etc.

Block diagrams and performance specifications of each system and examples of Synthetic Aperture Radar Data collected by both ERIM and JPL aircraft in support of Seasat-A premission experiments will be included in, and provided with the presentation.

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EVALUATION OF SPECTRAL CHANNELS AND WAVELENGTH REGIONS FOR SEPARABILITY OF AGRICULTURAL COVER TYPES

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ABSTRACT

The purpose of this study was to evaluate the spectral channels as well as wavelength regions -- visible, near infrared, middle infrared and thermal infrared -- with respect to their estimated probability of correct classification (P_c) in discriminating agricultural cover types. Multispectral scanner data in twelve spectral channels in the wavelength range of 0.4 to 11.7 μ m, acquired in the middle of July for three flightlines were analysed by applying automatic pattern recognition techniques. The same analysis was performed for the data acquired in the middle of August, over the same three flightlines, to investigate the effect of time on the results. The effect of deletion of each spectral channel as well as each wavelength region on P_c is given. Values of P_c for all possible combinations of wavelength regions in the subsets of one to twelve spectral channels are also given. The overall values of P_c were found to be greater for the data of the middle of August than the data of the middle of July.

INTRODUCTION

The purpose of this study was to determine the statistical separability of multispectral measurements from agricultural cover types for evaluation of spectral channels as well as wavelength regions -- visible, near infrared, middle infrared and thermal infrared. The data were analysed in subsets of one to twelve spectral channels, in the wavelength range 0.46 to 11.7 μ m for selected flightlines of the 1971 Corn Blight Watch Experiment¹. The agricultural cover types selected were: corn, soybeans, green forage (hay & pasture), and forest. In particular, the objectives of the study were: (1) to study the effect of deletion of each of the twelve spectral channels as well as each of the wavelength regions (visible, near infrared, middle infrared, and thermal infrared), on the statistical separability and corresponding estimated probability of correct classification of the agricultural cover types. (2) To develop a criterion for the evaluation of a combination of wavelength regions based on the estimation of its probability of correct classification of agricultural cover types. Based on this criterion, evaluate all possible combinations of wavelength regions in the subsets of one to twelve spectral channels out of twelve available channels. (3) To investigate the effect of time on these results.

LITERATURE REVIEW

Kumar (1972)² has done a thorough review of the general area of 'reflection and emission from plants'. The results of percent correct classification, obtained from the analysis of multispectral scanner (MSS) data by applying pattern recognition techniques, for a flightline divided into four classes (soybeans, corn, water and a mixture of stubble, diverted acres and pasture) were reported in the LARS annual report (1970)³. These are summarized as follows:

Performance	Percent Correct Classification Using the Following Wavelength Bands		
	3 Visible (ch.1,2,3) 1 Reflective IR (ch. 4)	3 Visible (ch.1,2,3) 2 Reflective IR (ch. 4,5)	3 Visible (ch.1,2,3) 2 Reflective IR (ch. 4,5) 1 Thermal IR (ch.6)
Training fields (4303 sample points)	86.8	91.9	93.6
Test fields (7135 sample points)	82.8	83.9	86.4

where

channel 1 = 0.40 - 0.44 μm , channel 2 = 0.55 - 0.58 μm , channel 3 = 0.66 - 0.72 μm
channel 4 = 0.80 - 1.00 μm , channel 5 = 1.50 - 1.80 μm , channel 6 = 8.00 - 14.0 μm

ch. denotes spectral channel

Coggeshall and Hoffer (1973)⁴ have analyzed the multispectral scanner data of a flightline having mostly forest. They have investigated the following in much detail: 1) determination of the optimum number of the 12 available multispectral scanner (MSS) wavelength bands to use for forest cover mapping with automatic data processing (ADP) techniques; 2) determination of the current capability to map basic forest cover types using MSS data and ADP techniques; and 3) determination of the relative utility, to forest cover mapping, of the four spectral regions available in the twelve channel MSS data (i.e., visible, and near, middle and thermal infrared).

They concluded from the tests of classification accuracy of six cover types of interest (deciduous forest, coniferous forest, water, forage, corn and soybeans), that the use of five wavelength bands would fulfill the dual requirements of adequate accuracy and moderate computer time. Their results also indicated that the thermal infrared wavelength region is desirable, but not necessary, for forest cover mapping, and that accurate classification of deciduous and coniferous forest cover can be achieved with the visible plus either the near or middle infrared spectral regions. However, the deletion of the thermal infrared region caused considerable confusion among the agricultural cover types.

Kumar and Silva⁵ have investigated the statistical separability of the spectral classes of blighted corn in much detail, data quantity (168 fields having 18804 sample points in ten flightlines) and depth. They found that the greater the difference between the blight levels, the more statistically separable they usually were. In addition, they found that the spectral classes of corn (Healthy and blighted) were most separable in the wavelength range 1.00 to 1.40 μm . Bauer (1974)¹ has discussed the results of 'wavelength band selection', obtained in the Corn Blight Watch Experiment.

Kumar and Silva (1977)^{6,7} analysed the multispectral scanner data in the wavelength range 0.4 to 11.7 μm for three flightlines. They found that in the subsets of one to six spectral channels, the combination of wavelength regions (where V, N, M and T denote the visible near infrared, middle infrared and thermal infrared wavelength regions, respectively): V, VM, VNM, VNMT, VVNMT, respectively, were found to be the best choices for getting good overall statistical separability of the agricultural cover types for the data acquired on July 16 as well as August 12. An effort was made to explain these results on the basis of spectral properties of agricultural cover types. The overall statistical separability of the agricultural cover types was found to be greater for the data of August 12 than the data of July 16. The author felt a definite need for doing a further analysis of similar nature to evaluate explicitly each spectral channel, each wavelength region and all possible combinations of wavelength regions for statistical separability and the corresponding probability of correct classification for agricultural cover types.

METHOD OF ANALYSIS

Multispectral scanner data in twelve spectral channels in the wavelength range 0.4 to 11.7 μm , collected with an optical-mechanical scanner at altitudes of 914 to 2133 meters (3000 to 7000 feet) over Western Indiana were analyzed by applying automatic pattern recognition techniques. The wavelength bands of these twelve spectral channels are given in Table I. The data of three selected flightlines, acquired in the middle of July of 1971, were analysed. Each of these three flightlines had fair or good amounts of each of the four agricultural cover types: corn, soybeans, green forage and forest. These three flightlines were selected carefully so that these combined could be considered to be representative of the four agricultural cover types in the Western Indiana.

Black and white photography and gray scale printouts of the spectral channels of the flightlines were used to aid in locating the boundaries of the fields on the LARS (Laboratory for Applications of Remote Sensing, Purdue University) Digital Display*. Sufficient number of

* The LARS Digital Display is a specially designed image display system linked to an IBM 360/Model 67 using a cathode ray tube as the pictorial medium for gray scale multispectral imagery.

fields of each agricultural cover type were selected carefully so that they could be assumed to be representative of the flightline.

Using the same three flightlines and twelve spectral channels an identical analysis was performed on the data acquired in the middle of August, 1971, to study the effect of time on the statistical separability of agricultural cover types. The multispectral scanner data was acquired on both dates (middle of July and middle of August) between 10.30 a.m. and 12:05 p.m. (local solar time). In addition, these data were of good quality and free from problems like lack of sufficient ground observations, excessive cloud cover, etc. The analysis was done for the data acquired in the middle of July and the middle of August, because corn and soybeans have reached their maximum vegetative growth by these times, and one month of time is sufficient for significant changes to occur in the spectral properties of agricultural cover types. The author wanted to avoid the analysis of data from late September afterwards, because soybeans are harvested in September-October. The author tried to keep all the variables other than time uniform in the two (middle of July and middle of August) sets of data as far as possible. For example, an effort was made to select about the same field boundaries for the two sets of data. A total of more than 600 fields taken from three flightlines were analysed.

Each field was treated as an independent unit and the fields of the same agricultural cover type were put in the same class. The sample points within each field were highly correlated. The LARSYS** statistics algorithm⁸ was used to compute the mean vector and covariance matrix (mean and standard deviation) of the classes. In the LARSYS statistics algorithm, cluster algorithm, and feature selection algorithm, each sample point is treated independently in order to make the system convenient and flexible for usage. A key assumption made in these algorithms is that the distributions of the classes are Gaussian. Histograms of the spectral classes defined above were used to check unimodality of the statistical distributions in individual channels. The classes were redefined to eliminate distinct multiple modes. Divergence is defined for any two density functions. In the case of normal variables with unequal covariance matrices, divergence in n spectral channels $C_1, C_2, \dots, C_n$, is given⁹ by

$$D(i,j | C_1, C_2, \dots, C_n) = 1/2 \operatorname{tr} \{ (\Sigma_i - \Sigma_j) (\Sigma_j^{-1} - \Sigma_i^{-1}) \} + 1/2 \operatorname{tr} \{ (\Sigma_i^{-1} + \Sigma_j^{-1}) (U_i - U_j) (U_i - U_j)^T \} \quad (1)$$

where

U and Σ represent the mean vector and covariance matrix respectively; $\operatorname{tr} A$ (trace A) is the sum of the diagonal elements of A .

A modified form of the divergence D_T , referred to as "transformed divergence", has a behavior^{8,10} more like the probability of correct classification than the divergence, D .

$$D_T = 2 \{ 1 - \exp(-D/8) \} \quad (2)$$

Transformed divergence has been used throughout this study.

Although divergence only provides a measure of the distance between two class densities, its use has been extended to the multiclass case by taking the average over all pairs¹¹. Let D_{Tij} denote the divergence between classes i and j of a certain flightline, then the average divergence over all class pairs of four classes (each agricultural cover was treated as a separate class) is given by

$$D_{TAVG} = \frac{1}{6} [D_{T12} + D_{T13} + D_{T14} + D_{T23} + D_{T24} + D_{T34}] \quad (3)$$

$$\text{Let } D_{TMIN} = \text{minimum of } \{ D_{T12}, D_{T13}, D_{T14}, D_{T23}, D_{T24}, D_{T34} \} \quad (4)$$

Swain⁸ (1972) has pointed out that one strategy is to select the subset of features for which

** LARSYS is the earth resources data processing software system of the Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Indiana.

the average transformed divergence, $\bar{D}_{TAVG}$ is maximum. While this strategy is certainly reasonable, there is no guarantee that it is optimal. Another strategy⁸ is to maximize the minimum divergence, $\bar{D}_{TMIN}$, i.e., to select the feature combination which provides the greatest separation between the hardest-to-separate pair of classes.

Let superscripts 1 and 2 with the symbol " $\bar{D}_T$ " denote the values of transformed divergence for the data acquired in middle of July and middle of August respectively. Let $\bar{D}_{TMIN1}^1$, $\bar{D}_{TMIN2}^1$, and $\bar{D}_{TMIN3}^1$ be the values of $\bar{D}_{TMIN}$ (see eq. (4)) in first, second and third flightline respectively for the data acquired in middle of July.

$$\text{Let } \bar{D}_{TAVG}^1 = \frac{1}{3} [\bar{D}_{TAVG1}^1 + \bar{D}_{TAVG2}^1 + \bar{D}_{TAVG3}^1] \quad (5)$$

$$\text{Similarly } \bar{D}_{TAVG}^2 = \frac{1}{3} [\bar{D}_{TAVG1}^2 + \bar{D}_{TAVG2}^2 + \bar{D}_{TAVG3}^2] \quad (5A)$$

$$\text{Let } \bar{D}_{TMIN}^1 = \text{minimum of } [\bar{D}_{TMIN1}^1, \bar{D}_{TMIN2}^1, \bar{D}_{TMIN3}^1] \quad (6)$$

$$\text{Similarly } \bar{D}_{TMIN}^2 = \text{minimum of } [\bar{D}_{TMIN1}^2, \bar{D}_{TMIN2}^2, \bar{D}_{TMIN3}^2] \quad (6A)$$

The LARSYS feature selection processor was used to find $\bar{D}_{TAVG}^1$ and $\bar{D}_{TMIN}^1$ in all possible combinations of one, two, three, four, five, six, seven, eight, nine, ten, eleven and twelve spectral channels out of the available twelve spectral channels (i.e., the number of all possible combinations of r spectral channels out of n spectral channels = $q = \frac{n!}{r!(n-r)!}$).

Throughout this analysis, the combinations of one through twelve spectral channels were ranked so as to get the descending order of $\bar{D}_{TAVG}^1$ and $\bar{D}_{TAVG}^2$ for the data of middle of July and middle of August respectively; for instance, for the data of middle of July, out of all possible combinations of r ($r = 1, 2, \dots, 12$) spectral channels out of twelve available channels, the channel combination which had the highest value of $\bar{D}_{TAVG}^1$ was ranked 'first'; the channel combination which had the second highest value of $\bar{D}_{TAVG}^1$ was ranked 'second' etc. In other words

$$\bar{D}_{TMAX}^1 \{ \text{subset of } r \text{ spectral channels} \} = \max \{ \bar{D}_{TAVG}^1 \}, \quad (7)$$

maximized over all possible subsets of r spectral channels out of the available twelve spectral channels for the data of middle of July. From the values of the average transformed divergence, classification accuracy can be reasonably predicted from the results of Swain et al. (1973)¹⁰.

Table I gives the wavelength interval and the corresponding wavelength region of each of the twelve spectral channels. The effect of deletion of each of the twelve spectral channels on $\bar{D}_{TMAX}^1$ (data of middle of July) and $\bar{D}_{TMAX}^2$ (data of middle of August), in terms of the corresponding estimated probability of correct classification (P_c) using the results of Swain et al.¹⁰ are given in table II. Similarly, Table III gives the effect of deletion of each of the wavelength regions -- visible, near infrared, middle infrared and thermal infrared -- on $\bar{D}_{TMAX}^1$ and $\bar{D}_{TMAX}^2$, in terms of the corresponding estimated probability of correct classification (P_c).

To fulfill one of the main objectives of the study -- evaluation of all possible combinations of wavelength regions in the subsets of one to twelve spectral channels -- the following criterion is proposed:

Each of 12 available channels of the multispectral scanner can be placed in one of the four wavelength regions -- visible, near infrared, middle infrared and thermal infrared, as shown in Table I. Thus, any combination of spectral channels can be called as the corresponding combination of the wavelength regions. For example, channel combination 1, 8, 10 and 12 is called "combination of visible, near infrared, middle infrared and thermal infrared wavelength regions", and is denoted by V N M T. For a given combination of wavelength regions, for example V N M T;

D_{TAVG} and the corresponding value of P_c using the curve of Swain et. al.¹⁰ was calculated for all possible combinations of four spectral channels out of twelve available channels that constitute the combination V N M T. The mean of these values of P_c was calculated for all possible combinations of wavelength regions in the subsets of one to twelve spectral channels, and is shown in Table IV for the data of middle of July as well as middle of August.

RESULTS AND DISCUSSION

The overall separability of green forage from the other agricultural cover types was found to be considerably lower than the corresponding separability of corn, soybeans and forest because the standard deviation of the mean response of green forage was largest among the agricultural cover types. This is because there was much natural variability in the spectral characteristics of hay as well as pasture. The overall separability of forest from other agricultural cover types was found to be considerably higher than the corresponding separability of corn, soybeans and green forage. Green forage and corn were hard to separate, because of considerable overlap in the values of their mean response, due to the large standard deviation of green forage. In addition, it was harder to separate corn from soybeans for the data of middle of July than for the data of middle of August.

Table II shows that deletion of channel 7 reduces P_c by about two percent for the data of middle of July as well as middle of August. The deletion of each of the other channels causes no reduction, or less reduction in the values of P_c , as compared to channel 7. Thus, deletion of any one of the twelve channels does not cause any substantial decrease in the values of P_c , in the subsets of one to eleven spectral channels.

As one would expect, Table III shows that the greatest separability of the agricultural cover types is obtained by using all of the twelve channels. However, an increase in the number of channels, used in a classification algorithm, requires a disproportionate increase in computer time⁴. Without doing a detailed analysis, it seems from Table III that the subset of five channels is likely to fulfill the dual requirements of adequate classification accuracy and moderate computer time. However, this conclusion is very preliminary, because no cost benefit analysis for the data was done.

Table III shows that deletion of each of the wavelength regions causes the following maximum reductions in P_c for the data acquired in the middle of July: visible (3.32, subset of four channels), near infrared (0.38, subset of ten channels), middle infrared (1.10, subset of two channels), thermal infrared (1.02, subset of four channels). The corresponding values of reductions in P_c for the data acquired in the middle of August are: visible (2.07, subset of one channel), near infrared (0.41, subset of ten channels), middle infrared (1.16, subset of two channels), thermal infrared (0.39, subset of eight channels). Thus, it appears that deletion of the visible wavelength region causes more reduction in P_c , as compared to any of the other wavelength regions. The deletion of near infrared wavelength region apparently causes relatively small changes in the values of P_c .

Table II shows that for greatest overall statistical separability of agricultural cover types, channel 7 (0.61 to 0.70 μ m, red channel) seems to be the best channel. It should be pointed out that the predominant pigments of the plant leaf absorb in the vicinity of 0.44 μ m, but only chlorophyll¹² absorbs in the red, in the vicinity of 0.64 μ m. The reason for channel 7 being the best channel may be that there are significant differences in the chlorophyll content of different agricultural cover types, which give rise to differences in their mean response in channel 7, and hence a relatively large value of average transformed divergence between them. An additional reason may be that the red wavelength region is extremely favorable for qualitative and quantitative description of soils¹³.

Table IV shows that in the subsets of one to six spectral channels, the combination of wavelength regions V, VM, VMT, VNMT, VVNMT, VVNNMT are found to be the best choices for the data of middle of July. Similarly, for the data acquired in the middle of August: T, NT, VNT or VMT, VNMT or VNMMT, VVNMT are found to be the best choices. These results are similar to the results obtained by Kumar and Silva^{6,9}, although a different criterion of evaluation of combinations of wavelength regions was used by them. Obviously, all the seven channels in the visible wavelength region in this multispectral scanner (MSS) are not necessary for getting good separability of the agricultural cover types.

In the data of middle of July as well as middle of August, V N M T is found to be the best choice in the subset of four channels. It indicates that each wavelength region is valuable in its own way. Because of the presence of water absorption bands in the middle infrared wavelength region, surface geometry of the target and the moisture content of its top layers (of the order of micrometers) determine its reflectance in the middle infrared region. This region is valuable because there are significant differences in the geometry of the surface, and/or moisture content of top layers of the agricultural cover types. The near infrared wavelength region is useful because substantial contrasts between the agricultural covers and soils occur in this region. Thus, this region is especially useful when there are substantial differences in the percentage ground covers of the agricultural cover types. The thermal channel (channel 12) contains information about the radiant temperatures of the targets in the wavelength region 9.3 to 11.7 μm . There are found to be significant differences in the radiant temperatures of the agricultural cover types. The radiant temperature of a plant can be found by doing an energy balance on it and it depends upon factors such as: radiation incident on the plant, plant geometry and size, spectral properties of the plant (including soil), percent ground cover, convection coefficient and transpiration rate of the plant, etc.². There are found to be differences in the values of the above variables for different agricultural cover like that give rise to differences in their radiant temperatures. Thus, in the subset of six spectral channels, irrespective of what other five channels were used, adding thermal channel to them usually increased the overall separability of the agricultural cover types.

In conclusion, it should be said that determining which combinations of one, two, ..., eleven spectral channels out of twelve available spectral channels give greatest overall statistical separability of the agricultural cover types is a complex problem, because statistical separability in any given combination of spectral channels depends upon many variables, such as quality of data in the spectral channels, quality and quantity of the ground truth available, time of acquiring the data, human decisions (number of fields, field boundaries to be selected, etc.) involved, environmental variables, plant variables, soil variables, etc.². However, determining which combinations of one through six wavelength regions give greatest overall statistical separability of the agricultural cover types is a relatively less complex problem (Table IV). It should be pointed out, although the flightlines analyzed had considerably different characteristics than the flightline analyzed by Coggeshall and Hoffer⁴ (Introduction), that many of the conclusions presented in this paper are the same as obtained by them. It means that although the analysis was done for three flightlines, the results obtained from this analysis may well be applicable to other flightlines having considerably different characteristics than these three flightlines. The overall statistical separability of the agricultural cover types was found to be greater for the data of middle of August than for the data of middle of July. It should be noted that many of the results obtained from the analysis of the data of middle of July are the same as those obtained from the data of middle of August. This means that, although the analysis was done for the data acquired at two different times, the results obtained from this analysis may well be applicable to the data acquired at some other times of the year.

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TABLE I. WAVELENGTH BANDS OF THE SPECTRAL CHANNELS

Channel N°	Wavelength Band (Micrometers)	Wavelength Region
1	0.46 - 0.49	visible
2	0.48 - 0.51	visible
3	0.50 - 0.54	visible
4	0.52 - 0.57	visible
5	0.54 - 0.60	visible
6	0.58 - 0.65	visible
7	0.61 - 0.70	visible
8	0.72 - 0.92	near infrared
9	1.00 - 1.40	near infrared
10	1.50 - 1.80	middle infrared
11	2.00 - 2.60	middle infrared
12	9.30 -11.70	thermal infrared

TABLE II. EFFECT OF DELETION OF EACH CHANNEL ON THE PERCENTAGE PROBABILITY OF CORRECT CLASSIFICATION

When using a subset of	Percentage probability of correct classifica- tion estimated from $\bar{D}_{TMAX}$ (see eq.(7)) when using all the available channels	Percentage probability of correct classifica- tion estimated from $\bar{D}_{TMAX}$ when deleting a channel from the avai- lable channels	Percentage probability of correct classifica- tion estimated from $\bar{D}_{TMAX}$ when using all the available channels	Percentage probability of correct classifica- tion estimated from $\bar{D}_{TMAX}$ when deleting a channel from the avai- lable channels
	(A)	(A)	(B)	(B)
one channel	84.63	Same (84.63) except de- letion of channel (ch.)7 reduced it to 82.64.	86.18	Same (86.18) except de- letion of channel (ch.) 7 reduced it to 84.11.
two channels	89.28	Same (89.28) except de- letion of ch. 7 and 10. Deletion of ch. 7 and ch.10 reduced it to 88.55 and 89.26 respectively	91.88	Same (91.88) except de- letion of ch. 7 and 11. Deletion of ch. 7 and ch.11 reduced it to 91.57 and 91.09 respec- tively.
three channels	91.58	Same (91.58) except dele- tion of ch. 7,11 and 12. Deletion of ch.7, ch.11 and ch. 12 reduced it to 90.85, 91.44 and 90.72 respectively	94.64	Same (94.64) except de- letion of ch. 3,8 and 11. Deletion of ch.3, ch. 8 and ch.11 reduced it to 94.52, 94.42 and 94.56 respectively.
four channels	93.43	Same (93.43) except dele- tion of ch.4,7,11 and 12. Deletion of ch.4, ch.7, ch.11 and ch.12 reduced it to 93.13, 93.11, 93.36 and 92.41 respectively.	96.33	Same (96.33) except dele- tion of ch. 4,8,11 and 12. Deletion of ch.4, ch.8, ch.11 and ch.12 reduced it to 96.28, 96.27, 96.23 and 96.25 respectively.

Note: The effect of deletion of a channel in the subsets of five to twelve channels on the percentage probability of correct classification estimated from $\bar{D}_{TMAX}$, P_c , was rather small except for channel 12, i.e., the maximum reduction in $P_c = 0.20$ for case (A) and 0.3 for case (B) except for channel 12. The effect of deletion of channel 12 can be found in the Table III. The values of P_c were estimated from the values of $\bar{D}_{TMAX}$ using the curve of Swain and King (1973)¹⁰.
(A) refers to data acquired in the middle of July. (B) refers to the data acquired in the middle of August.

TABLE III. EFFECT OF DELETION OF EACH WAVELENGTH REGION ON THE PERCENTAGE OF CORRECT CLASSIFICATION

Number of channels in the subset Values of probability of correct classification estimated from $\bar{D}_{TMAX}$ (see eq.(7))

	A ₀	A ₁	A ₂	A ₃	A ₄	B ₀	B ₁	B ₂	B ₃	B ₄
one	84.63	82.00	84.63	84.63	84.62	86.18	84.11	86.18	86.18	86.18
two	89.28	87.22	89.28	88.18	89.28	91.88	91.56	91.88	90.72	91.88
three	91.58	88.74	91.58	91.00	90.72	94.64	93.89	94.34	94.42	94.64
four	93.43	90.11	93.43	92.8	92.41	96.33	95.46	96.27	96.08	96.25
five	94.34	92.01	94.34	93.91	93.55	97.22	96.51	97.17	96.79	97.02
six	94.95	np	94.88	94.40	94.23	97.73	np	97.60	97.24	97.43
seven	95.33	np	95.22	94.78	94.68	98.02	np	97.75	97.39	97.73
eight	95.63	np	95.32	95.09	95.05	98.21	np	97.84	97.51	97.82
nine	95.89	np	95.62	95.26	95.31	98.30	np	97.90	97.60	98.02
ten	96.08	np	95.70	95.38	95.48	98.36	np	97.95	97.68	98.11
eleven	96.20	np	np	np	95.58	98.40	np	np	np	98.14
twelve	96.30	np	np	np	np	98.20	np	np	np	np

Note: 'np' denotes that it was not possible to have a combination of m (m = 1,2... 12) spectral channels after deleting the spectral channels in a particular wavelength region. This table gives the values of percentage probability of correct classification (P_c) estimated from the values of $\bar{D}_{TMAX}$ (see eq.(7); Swain and King (1973)).¹⁰ A₀, A₁, A₂, A₃ and A₄ denote the values of P_c when using all available channels; deleting spectral channels in the visible, near infrared, middle infrared and thermal infrared wavelength regions respectively for the data acquired in the middle of July. B₀, B₁, B₂, B₃ and B₄ denote corresponding quantities as A₀, A₁, A₂, A₃ and A₄ respectively for the data acquired in the middle of August.

TABLE IV. EVALUATION OF COMBINATIONS OF WAVELENGTH REGIONS

r = 1	(A) P _c	(B) P _c	VVVM	90.5	92.6	(5V)T	92.3	95.8	(6V)NN	92.5	96.4	r = 11	(A) P _c	(B) P _c
			VVVT	90.2	92.0	(4V)NN	92.3	96.3	(6V)NM	93.5	96.7			
			VVNN	89.7	93.5	(4V)NM	92.4	96.5	(6V)NT	94.0	96.7			
V	81.8	82.8	VVNM	90.7	95.5	(4V)NT	92.4	96.4	(6V)MM	92.5	96.6	(7V)NNMM	95.9	97.7
N	71.1	80.7	VVNT	90.8	95.5	(4V)MM	92.3	96.4	(6V)MT	95.3	96.8	(7V)NNMT	96.1	97.7
M	81.7	85.0	VVMM	90.3	92.6	(4V)MT	92.6	96.5	(5V)NNM	94.1	96.8	(7V)NNMT	96.1	98.0
T	80.7	86.0	VVMT	91.5	95.8	VVVNNM	92.4	96.5	(5V)NNT	94.7	96.8	(6V)NNMMT	96.2	98.1
			VNNM	90.6	95.3	VVVNNT	92.5	96.5	(5V)NMM	94.0	96.9			
r = 2	(A) P _c	(B) P _c	VNNT	90.5	95.6	VVVNMM	92.4	96.6	(5V)NMT	95.5	97.1	r = 12	(A) P _c	(B) P _c
			VNMM	90.6	95.6	VVVNMT	92.6	96.7	(5V)MMT	95.5	97.1			
			VNMT	91.6	96.1	VVVMMT	92.6	96.7	(4V)NNMM	93.9	97.1			
VV	85.0	88.4	VMMT	91.2	95.8	VVNNMM	92.3	96.6	(4V)NNMT	95.5	97.1	(7V)NNMMT	96.3	98.2
VN	85.9	89.1	NNMM	88.9	94.1	VVNNMT	92.7	96.7	(4V)NNMT	95.6	97.5			
VM	87.5	90.5	NNMT	89.8	95.3	VVNNMT	92.8	96.9	VVVNNMMT	95.6	97.6			
VT	86.9	89.4	NNMT	89.6	95.8	VNNMMT	92.5	96.8						
NN	77.0	86.1							r = 9	(A) P _c	(B) P _c	Note: r = subset of sp		
NM	85.4	89.7	r = 5	(A) P _c	(B) P _c	r = 7	(A) P _c	(B) P _c				column (A) denot		
NT	84.4	91.1							(7V)NN	92.6	96.6	for the data acqu		
MM	85.4	87.6							(7V)NM	93.6	96.8	July. The colum		
MT	86.7	90.5	5V	88.8	93.3	7V	89.5	94	(7V)NT	94.7	96.8	lues of P _c for t		
			(4V)N	91.6	95.8	(6V)N	92.4	96.6	(7V)MM	93.5	96.7	middle of August		
r = 3	(A) P _c	(B) P _c	(4V)M	91.7	95.8	(6V)M	92.5	96.7	(7V)MT	95.6	96.9	combination of w		
			(4V)T	91.7	95.3	(6V)T	92.4	96.4	(6V)NNM	94.7	97.0	example, VNMT: D		
VVV	86.9	89.4	VVVNN	91.7	96.0	(5V)NN	92.5	96.8	(6V)NNT	95.5	97.0			
VVN	87.7	91.8	VVVNM	91.8	96.2	(5V)NM	92.6	96.7	(6V)NMT	95.6	97.1	all possible com		
VVM	89.4	91.8	VVVNT	92.0	96.2	(5V)NT	93.5	96.7	(6V)NMM	95.6	97.1	channels constit		
VVT	88.2	90.9	VVVMT	91.8	96.3	(5V)MM	92.5	96.9	(6V)NMT	95.8	97.3	of wavelength re		
VNN	87.8	91.9	VVNM	91.6	96.2	(5V)MT	94.7	96.8	(6V)MMT	95.8	97.3	of these values,		
VNM	89.6	92.4	VVNT	91.9	96.2	(4V)NNM	93.5	96.7	(5V)NNMM	95.5	97.3	rect classificat		
VNT	89.5	92.5	VVNNT	91.8	96.3	(4V)NNT	93.7	96.7	(5V)NNMT	95.8	97.5	using the curve		
VMM	89.1	91.1	VVNMT	92.2	96.5	(4V)NMT	94.7	96.9	(5V)NNMT	95.8	97.5	(1973). V, N, M		
VMT	90.3	92.5	VVMMT	92.0	96.4	(4V)MMT	94.7	96.8	(4V)NNMMT	95.9	97.7	near infrared, n		
NNM	87.6	92.4	VNNMM	91.7	96.3	VVVNNMM	93.5	96.8				mal infrared wav		
NNT	86.7	92.4	VNNMT	92.0	96.5	VVVNMT	94.7	96.8	r = 10	(A) P _c	(B) P _c	tively.		
NMM	87.2	92.0	VNNMT	92.0	96.4	VVVNMT	94.8	97.1				5V≡VVVVV, 4V≡		
NMT	87.6	92.2	NNMMT	91.6	96.3	VVNNMMT	94.2	97.1	(7V)NNM	95.5	97.1			
MMT	88.0	92.0							(7V)NNT	95.8	97.1			
			r = 6	(A) P _c	(B) P _c	r = 8	(A) P _c	(B) P _c	(7V)NMM	95.5	97.5			
									(7V)NMT	95.9	97.5			
									(7V)MMT	95.9	97.6			
VVVV	87.8	90.1	6V	89.4	93.6	(7V)N	92.0	96.3	(6V)NNMM	95.8	97.6			
VVVN	89.4	92.4	(5V)N	92.2	96.1	(7V)M	92.2	96.3	(6V)NNMT	96.1	97.6			
cont.			(5V)M	92.3	96.2	(7V)T	92.2	95.8	(6V)NNMT	96.1	97.7			
			cont.			cont.			(5V)NNMMT	96.2	98.1			

THERMAL IMAGERY FOR CENSUS OF UNGULATES

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ABSTRACT

A Daedalus thermal linescanner mounted in a light single engine aircraft was used to image the entire 270 square kilometers within the fenced perimeter of Elk Island Park, Alberta, Canada. The data were collected during winter, 1976 in morning and midday (overcast conditions) processed and analyzed to obtain a number for total ungulates. Five different ungulate species were present during the survey.

Ungulates were easily observed during the analysis of line-scanner imagery and the total number of ungulates was established at 2175 compared to figures of 1010 and 1231 for visual method aerial survey results of the same area that year. It was concluded that the scanner was much more accurate and precise for census of ungulates than visual techniques. Advantages over visual survey methods include: no technician effect; no observed fatigue; operation at night, early morning and without snow cover; detection of camouflage or neutral coloured animals; accurate results, repeatable results, and habitat permanently recorded. Disadvantages include: restricted in severe terrain, southern latitudes; sex of animal is not recorded; species separation is limited to different sized animals; and cost is equal to or higher than visual methods. Applications of the thermal scanner include total counts of ungulate concentrations or high densities, sampling programs or animal habitat relationships (both habitat and animal are represented on imagery). Cost is comparable to helicopter census work.

1. INTRODUCTION

The obtaining of reliable census information is one of the major difficulties in the management of wildlife populations. Most methods in use today for counting or estimating ungulate populations rely on visual observations from aircraft. Experiments over the last few years have caused many workers to move to rotary wing aircraft from fixed wing aircraft or to the use of block rather than transect methodology or both (Evans, et al. 1966; 1968; Bergerud, and Manual, 1969; Lynch 1975). Though these changes have given better results, many factors still bias the results of aerial census work. Internal factors (those related to the observer and aircraft, ie. tiredness, nausea, experience, type of aircraft, visibility, and external factors, ie. weather (snow cover, temperature), animal movement and behavioral patterns, coloration and habitat are discussed by Graham and Bell (1969) and Heyland (1976) in relation to their effects on census reliability.

These problems of accuracy and precision in census work have led wildlife managers to experiment with new techniques in an effort to obtain increased

reliability. Considerable hope has been expressed regarding the potential of a thermal technique that would detect warm blooded animals in a cold environment (Zanon, 1964; Bartholomew and Hoffer, 1966, and Cain, 1966). Field tests using thermal infrared scanners have been conducted in several areas but few results have been published. Croon, et al. (1968) published the most widely known test; in which it was concluded that scanners could give the most reliable counts of any method available, but that the technique was expensive and did not work well in coniferous habitats.

The potential of the method demonstrated by Croon and the availability of a high resolution scanner in an available, light aircraft prompted the design of a new study in both economics and reliability. Elk Island National Park was selected as an ideal test area for the thermal method because the park is of limited size, fenced, has very few conifers, and has a high density of wild ungulates (hooved animals). Parks Canada was receptive to the idea of applying the technique there and a pilot program was designed. The objectives of the study were; 1) to obtain a reliable estimate of the total number of ungulates, 2) to evaluate the potential of imagery from the thermal linescanner data to provide separate species information and 3) to evaluate the effectiveness of the scanner as a function of different weather conditions, times of day, altitudes and possible unknown parameters. The following text summarizes the project and discusses the results of this pilot program.

2. METHODS

The scanner used for data collection was a quantitative Daedalus thermal linescanner and mounted in a Piper Cherokee Six and later in a Piper Aztec. The scanner was used with an 8-14 micron sensor having a 1.7 milliradian instantaneous field of view (IFV) which results in an IFV of 52 cm. at an altitude of 305 m. above ground level (AGL). The data were collected at an above ground altitude of approximately 300 m. which provided a 12.7 cm. strip of film (when processed) representing a 500 m. width of the ground surface. A total of 862 line km. were flown on three separate surveys.

The imagery was processed by Canada Centre for Remote Sensing and interpreted in 12.7 cm. wide negative format. Interpretation of all imagery was done by two biologists, Keith Baker, Wildlife Resources Manager for Parks Canada and Marc Wride, INTERA. After completely analyzing the imagery individually, both collaborated to reanalyze the data simultaneously and arrive at a mutually acceptable estimate for each strip of film.

Density slicing was experimented with using the facilities at Alberta Remote Sensing Centre in Edmonton to evaluate the technique for more machine-oriented interpretation methods.

3. RESULTS AND DISCUSSION

Comparison of Visual and Thermal Methods

Results from the analysis by interpreters A and B did not diverge more than 9.0 percent and were as low as 2.0 percent (Table I). In most cases, interpreter B returned a larger number; usually the result of locating animals which had not been observed by the first interpretation (all animals were marked by each interpreter). The second time through the data both interpreters analyzed each strip of film simultaneously and arrived at a mutually agreed upon number of animals. Again previously unseen animals were located. The average of the two interpreters first result compared to the combined result for each area (including total) shows that the collective or combined results were larger than the average of the two separate counts by approximately 10 percent. This consistent increase was attributed to the combined effort and additional inter-

pretation time spent on the data. Many of the animals located during the combined effort were characterized by small size or minimal contrast on the film making detection difficult. More thorough analysis by the interpreters coupled with increased experience during a first analysis should reduce this discrepancy and increase precision.

The final estimate of total ungulate numbers was 2175 (Table II). Two visual aerial surveys conducted by Parks Canada the same winter; one in December 1975 and one in March 1976, produced estimates of 1010 and 1231 ungulates respectively. These included 356 bison (*Bison bison*), most of which were collected, penned and counted. The higher March figure of 1231 is 57 percent of the infrared result (2175). Parks usually adds 25 percent to these raw data excepting bison because it is common knowledge that numbers from visual aerial census are consistently below actual population figures. This would raise the estimate to 1450 or 67 percent of the thermal scan number. This large difference between the estimates from the aerial survey and the thermal scan has some basis for explanation.

A recent test on aerial census accuracy of penned moose (*Alces alces*) in Alaska by Le Resche and Rausch (1974) showed the average detection rate for experienced observers to be 68 percent of moose present. Inexperienced observers saw only 43 percent. Habitat and relief were factors, however, and as Elk Island is flat and primarily deciduous, under good snow conditions, experienced observers should see a higher percentage; perhaps 75-85 percent of the moose present. Such a high percentage would be possible only under optimum conditions, and snow conditions were not optimum in the March survey. Le Resche and Rausch (1974) showed poor conditions to cause up to a 50 percent reduction of sightings compared to optimum conditions. In addition to these there is the problem of detectability coefficients for the different species. Moose are easily observed in comparison to elk (*Cervus canadensis*) and especially deer (*Odocoileus* spp.) and a coefficient for this characteristic was not and usually is not included in visual surveys. For these reasons it is concluded that the visual estimate is probably on the order of 60 percent of actual numbers and that the thermal scan figure for total ungulates is a more accurate estimate.

There are sources of potential inflation of the thermal scan number including: solar heated objects, vacant beds and other animals. It is the opinion of both interpreters after viewing the imagery, that counting of solar heated objects could not be responsible for a significant inflation of data in this study. Evaluating the potential for bias from counting vacated beds of animals is more difficult. Marble (1967) reported that the apparent temperature of beds was 1 to 2°C warmer than the animal at the time of vacation, but dropped below animal temperature within one minute of the time the animal left. Driscoll (1976) indicated that tests with thermal scanning of penned deer showed sensing of beds to be no problem. Preliminary studies the temperature change of vacated beds in the Calgary Zoo field pens for moose, deer and bison indicate a more prolonged temperature retention than before suspected. Light snow and warm ground temperatures may have influenced this to a large degree and additional research is necessary.

It is also possible that a number of animals were omitted, as an animal behind a tree might not be "seen" by the scanner. Comparison of areas with overlapping coverage did not show this to be a significant problem, although occasionally additional animals were located in this manner. It was concluded that the thermal scan number for total ungulates may be subject to limited inflation, which would be partially compensated for by a few missed animals, the total effect being not significant. This is, however, a preliminary conclusion and additional research is planned.

Separation of Species

Separation of species using the scanner data was found by both interpreters to be quite difficult. Bison could be separated by their gregarious social

patterns and preference for open and lakeshore habitat (Figure 1). Moose could be generally recognized by their non-social spatial orientation (Figure 2). Although this separation approach has merit and utility it is limited in reliability by the potential to identify social groups of elk and deer as bison or single bison and elk as moose.

Studies by Hammel (1956) on emissivity values of different animals have shown most animals to be very similar. Relative size of the "hot spot" on the imagery is often helpful but can be misleading as there is some variance in hot spots due to processing on different filmstrips, metabolic rate (activity of animal) and orientation to scanner. This fact makes machine processing questionable. It is possible that a technique of species separation may be developed and refined which could be adequate for reasonably accurate results, but the data collected in this study were not preceded by the necessary testing to allow this type of interpretation. In many areas the number of species may be one or perhaps two different sized animals. In cases of this type or if the ratio of animals is known from preliminary sampling, the system can be used for obtaining accurate total numbers and adequate estimates of species. It appears however that visual census methods will for the foreseeable future provide better information on sex and age of ungulates.

Interpretation Techniques

Interpretation of imagery was done visually, although some colour and black and white density slicing was done on a trial basis. Density slicing did not isolate the animals as well as visual interpretation; insensitivity of the slicing caused inclusion of other objects having nearly the same temperature. A number of variables in animal temperature could be more easily accounted for visually than by machine, including: animal orientation and small differences in processing results. Visual methods will probably remain the most effective method of analysis for the foreseeable future.

Operational Constraints

Croon et al. (1968) established a series of optimum conditions for thermal scanning of ungulates which included: open or leafless habitat, snow cover, no wind, high overcast sky, and daytime overflight. He stated that as conditions depart from these optimum conditions the image quality decreases. This was found to be true in this study, but to a lesser degree than expected as imagery collected during less than optimum conditions was still found to be of operational quality. Snow cover was not a necessary requirement nor was a high overcast sky. Absence of wind, cold ground (or snow) and open canopy were, however, determined to be necessary for operational quality imagery. Under these conditions, early morning flights produce good quality imagery and allow census work to be done during the active part of the animals' day. These results indicate thermal scanning is a feasible operational technique under a broader combination of weather conditions than previously thought. This capability offers an important advantage over visual methods because such flexibility offers reliable census numbers in fall and late winter when poor snow conditions or absence of snow render visual methods unreliable. Additional work during these seasons and conditions is required to verify this observation as is work in coniferous habitat and rough terrain conditions.

Cost Effectiveness and Application

The cost of scanning is higher than normal light fixed wing operations because of technical manpower requirements, scanner costs and processing costs, however, most fixed wing census operations have been or are being replaced by helicopter techniques. Some agencies are flying samples and others are making attempts at complete coverage of their game habitat. This variance in platforms and methodology makes a cost comparison difficult, but, generally it can

be concluded that thermal census is comparable in cost to helicopter methodology. This cost comparison is made on the basis of total services and data product for the thermal census versus airplane and fuel costs for visual census. Visual census man-time is not included, however, it is recommended that the agency do their own interpretation which equalizes this discrepancy.

Thermal scanning for ungulate census is more accurate than visual techniques for actual counting for numbers, but this accuracy does not always warrant using the thermal technique. Considering cost and benefits it was concluded that thermal scanning methodology has optimum application in three types of roles: 1) total counts of ungulates in wintering areas; 2) statistical sampling in relatively homogenous habitat or stratified habitat; and 3) in research applications of animal-habitat relationships. All of these applications will be most effective if the cover is primarily deciduous, terrain is moderate and if the species of interest is locally predominant in that size category (eg. moose vs. deer). The thermal system will count more effectively than visual means in coniferous habitats but reliability of any census method is suspect in such conditions.

Populations of ungulates often concentrate in wintering areas to obtain food and shelter. Costs of scanning such areas are not excessive and the data collection can be done in early morning when animals are in more open habitat. River valleys would be among the more ideal situations. Elevation changes in river valleys are predictable and can be compensated for.

Quadrat sampling of homogenous or stratified habitat can be done effectively and the area done confirmed as the designated strata and statistically analyzed for precision. This application has merit compared to visual work as precision and accuracy have been lacking in visual work, making results suspect.

Research data requirements for an animal-habitat relationship study could justify instigating a thermal survey, but this type of information is available as a spin-off or by-product from doing a thermal census for census purposes, increasing cost effectiveness. The scanner records vegetation and other environmental features well enough that they are easily correlated with normal aerial photos or good vegetation maps. Also, these data are easily stored and could be used later if a question on use should arise. The flexibility of scanning at different times of the day over a 24 hour period allows documenting the location of entire herds or single animals in relation to vegetation, etc. Animals are generally not disturbed by a fixed wing aircraft flying 300 m. or more above ground level which reduces bias from induced movement. There is currently no radio telemetry technique that can provide such complete or exact information on animal location relative to habitat.

4. CONCLUSIONS

The thermal scan resulted in a total number of ungulates that was higher than both of the aerial census estimates, and more reasonable considering the bias inherent in visual census documented in other studies. The thermal scan did not provide enough information for reliable separation of animal species, however, additional work on this problem (currently underway) could show separation of different sized species. Spacial relationships of bison and moose were easily detected and could be helpful in species separation. Visual interpretation of thermal imagery appears to be the best method available at the present time. The conditions under which the linescanner can be operated are broader than previously thought, enhancing or increasing the potential of the method for operational use, however, wind and extreme terrain are limiting. Although scanning is expensive relative to fixed-wing aerial survey, it is approximately equal to helicopter techniques and the improved accuracy of the method justifies use of the method for statistical sampling, census of winter habitat (ie. river valleys or key winter areas) and for habitat-animal distribution studies.

Additional studies to refine the technique and determine operational limitations are underway and results will be available in the near future.

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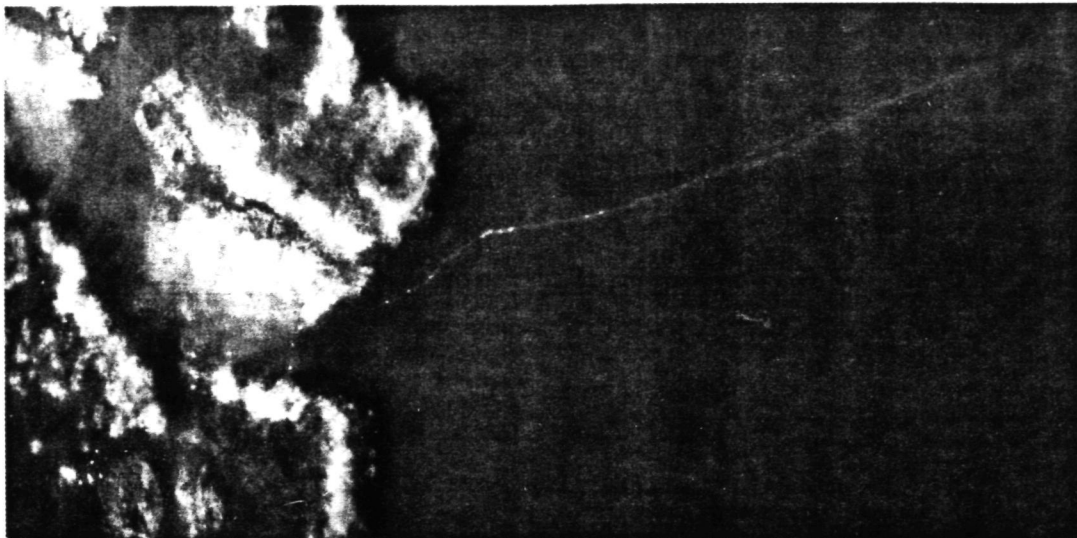


FIGURE 1. Bison on frozen lake. Contact print of infrared imagery showing bison (Bison bison) as white "hot spots" in aspen (Populus tremuloides) (lighter areas) and shrub, grassland (darker areas) communities between two frozen lakes. Note the dense spatial pattern of the bison. Scale 1:4800.

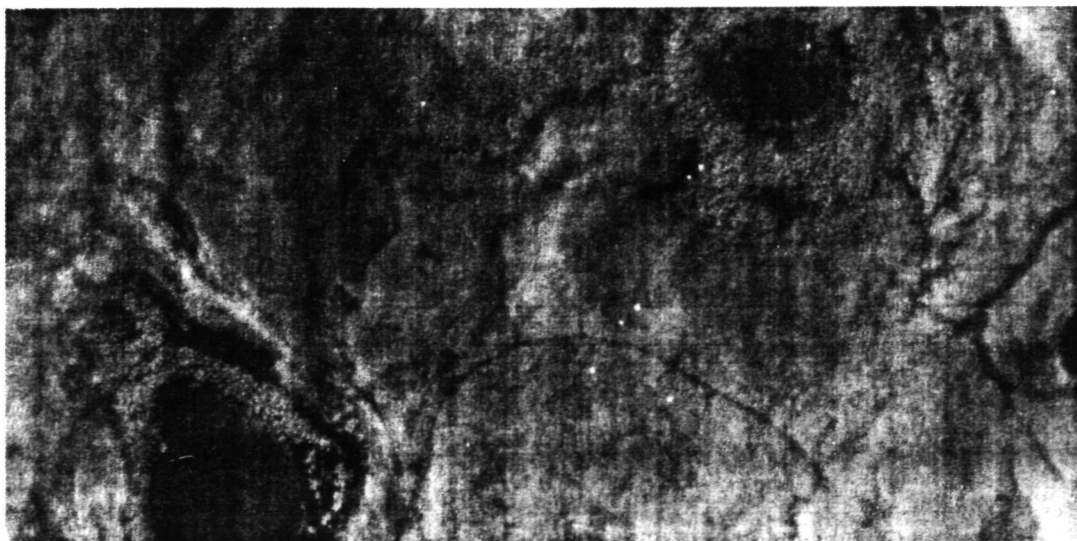


FIGURE 2. Moose in Aspen. Contact print of infrared imagery showing two ungulates (white spots center of photograph), probably moose (Alces alces) in a non social spatial orientation in an aspen community (lighter areas) near a muskeg (darker area).

TABLE I. RESULTS OF INFRARED IMAGERY INTERPRETATION
AT ELK ISLAND PARK, 1976.

Section of Park	Interpreter	Number of Animals		Total
		Certain	Uncertain	
Northern	A ¹⁾	571	63	634
	B	551	38	589
	AVE $\frac{(A+B)}{2}$	561	50.5	611.5
	A,B combined ²⁾	659	----	659
Centre	A	968	41	1009
	B	1053	33	1086
	AVE	1010.5	37	1047.5
	A,B combined	1164	----	1164
Total Main Park	A	1539	104	1643
	B	1604	71	1675
	AVE	1571.5	87.5	1659
	A,B combined	1830	----	1830
Isolation	A	288	----	288
	B	297	14	311
	AVE	292.5	14	300
	A,B, combined	345	----	345
Total Park	A	1827	----	1827
	B	1901	85	1986
	AVE	1864	85	1949
	A,B combined	2175	----	2175

- 1) A - Parks Canada Interpreter
B - INTERA Interpreter

- 2) A,B combined - both interpreters analyzed each strip of film together and agreed on the number of animals observed.

TABLE II. RESULTS OF AERIAL SURVEYS OF UNGULATES
IN ELK ISLAND PARK 1971 - 1976.

Section of Park	Date	Moose	Animal Deer	Count Elk	Bison ¹⁾	Total
Main Park	Dec. 75	231	27	200	268	726
	Mar. 76	217	16	430	268	931
Isolation	Dec. 75	337	106	211	356	1010
	Mar. 76	349	78	448	356	1231

1) Known number, not estimated.

REMOTE SENSING IN OPERATIONAL RANGE
MANAGEMENT PROGRAMS IN WESTERN CANADA

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ABSTRACT

During 1976, a pilot program was carried out in Western Canada to test remote sensing under semi-operational conditions and display its applicability to operational range management programs. Four agencies were involved in the program - two in Alberta and two in Manitoba. Each had different objectives and needs for remote sensing within their range management programs, and each was generally unfamiliar with remote sensing techniques and their applications. Personnel with experience and expertise in the remote sensing and range management fields worked with the agency personnel through every phase of the pilot program - planning, data acquisition, training and interpretation of remote sensing imagery (mainly false colour infrared photography at three different scales, plus Landsat imagery), evaluation of results, and preparation of recommendations for implementation into their own agency programs. Provision of pertinent inventory and monitoring data and cost-effectiveness were considered primary factors. Results indicate that these agencies have found remote sensing to be a cost-effective tool and will begin to utilize remote sensing in their operational work during ensuing seasons.

1. INTRODUCTION

The rangelands of Canada cover a wide geographical area and constitute a valuable resource in terms of livestock and wildlife, timber, recreation, fossil fuel and other resources. Increasing demand on such resources necessitates intensification of management which will maximize productivity and allocate multiple use of rangelands, as most range managers are now aware. They are challenged with more intensive management of lands under their current jurisdiction, as well as with inventory of new lands, and provision of accurate and detailed information for multi-use policy decisions in rangeland areas.

Remote sensing can assist the range manager by maximizing efficiency, expanding area of coverage, reducing intervals of range monitoring, and permitting economical inventory of remote areas. Management agencies should thus be developing management plans and strategy to include up-to-date remote sensing techniques. Such a development has in the past been unduly delayed since these agencies, with limited manpower, budgets and exposure to remote sensing, had to generate such expertise from within themselves. The pilot program approach has been proposed as a means of transferring remote sensing from research into operational spheres; each interested agency is exposed to the techniques of remote sensing, and to the potential benefits for their individual range management programs, while developing expertise in application of remote sensing within their own agency over a relatively short time period. This approach was tested during 1976 when the Canada Centre for Remote Sensing sponsored a pilot program under the management of INTERA Environmental Consultants Ltd., involving four range management agencies in western Canada.

A pilot program is a necessary intermediary stage between research-oriented, feasibility studies and fully operational applications of remote sensing. During this program, remote sensing technology is tested under semi-operational conditions and the results display its applicability to the operational programs of range management agencies, allowing each agency to assess the value of remote sensing with respect to their own needs.

Four of the eleven major range management agencies in western Canada participated in the 1976 project (their areas of jurisdiction are seen in Figure 1). These were (1) the Forest Land Use Branch, Alberta Forest Service, Department of Energy and Natural Resources (Edmonton); (2) the Lands Division, Alberta Department of Energy and Natural Resources (Lethbridge); (3) the Crown Lands Division, Manitoba Department of Agriculture; and (4) the Renewable Resources Division (Wildlife), Manitoba Department of Renewable Resources and Transportation Services. The latter two agencies were considered together as they shared the same study area and remote sensing imagery. Thus, there were three separate pilot programs conducted under this contract.

The range agencies were directly involved in the planning of the pilot program, the data acquisition (both in the air and on the ground), the interpretation of the imagery, and the subsequent implementation into their individual management systems. Since range managers often are not experienced in these areas, and require assistance in carrying out such a program so that the results would be useful and directly applicable to their work, INTERA coordinated the program for each agency, ensuring efficient and meaningful data acquisition, interpreter training, and provision of assistance in making recommendations for future operational programs.

2. STRUCTURE OF 1976 PILOT PROGRAMS

A basic four-stage pilot program was designed which allowed for flexibility in application to the different agencies involved: (1) program planning, (2) data acquisition, (3) training and interpretation, and (4) program evaluation. The first stage consisted of establishing the objectives, current programs and needs of each agency with respect to inventory and monitoring the rangelands under their jurisdiction, and based on that information, planning a pilot program. This included choosing a study area, planning the ground surveys, discussing remote sensing imagery types and scales, and all other details. INTERA worked with the agency personnel in an advisory capacity, their level of involvement differing with the experience of the agency personnel and the needs of that agency program. The choice of remote sensing imagery, the scales and times of year for data acquisition were based on the recommendations of a 1975 feasibility study (Intera, 1975) although changes were made according to agency preference and need. Thus, the remote sensing included false colour infrared (FCIR) photography at large, medium and small scales, Landsat imagery (Bands 5 and 7), and in one case small format colour and colour infrared photographs.

The second stage involved the airborne and ground data acquisition. INTERA participated in the ground surveys to ensure proper data collection and supervised the processing of the data. Most of the FCIR photography for the three programs was flown by the first week of August, although some was obtained later in the season as requested by the agency involved. The ground surveys were timed with the remote sensing overflights where possible.

For the third stage, INTERA prepared a three-day training course as an introduction to remote sensing and its application to rangeland management. The level of training was gauged to the varying experience of the range managers with remote sensing. The interpretation of the remote sensing imagery was carried out by the agency personnel with assistance from INTERA when necessary (this varied from agency to agency according to their needs). In the final stage, program evaluation, meetings were held with all of the personnel involved to discuss the pilot program in all its aspects, the results of the interpretation

of the remote sensing imagery and its application to operational range management programs, and to make recommendations for future use of remote sensing by the agency. A report was then compiled for each agency, documenting each stage of the program, its results, conclusions and recommendations (Thompson & Yule, 1977; Thompson & Klumph, 1977, Thompson et al, 1977).

3. DESCRIPTION OF THE THREE AGENCY PILOT PROGRAMS

Table 1 provides a summary of the three agency pilot programs carried out during 1976, including details on their study areas, remote sensing imagery, ground survey data, and methods of remote sensing interpretation. Their individual agency objectives for participation in the program were varied, thus emphasizing the need for flexibility in the basic pilot program. The Alberta Forest Service (Edmonton) wanted to use remote sensing to partially replace time-consuming ground surveys and thus reduce the 15-year interval of monitoring their grazing allotments (there are about 90 allotments in the Alberta Rocky Mountain Forest Reserve covering 3650 square kilometers). Using remote sensing imagery for inventory and monitoring of range species and range condition, existing allotment management plans could be modified according to current status of the range, and management thus intensified.

The Alberta Lands Division (Lethbridge) was primarily interested in estimating range productivity during the grazing season, on their 24,000 square kilometers of grazing leases in the short and mid-grass prairie areas of southern Alberta. Their goals included using remote sensing for more intensive and more frequent inspections of their grazing lands to ensure proper management.

Within the Manitoba pilot program, the Department of Agriculture (Crown Lands) is currently establishing a range management program, and wanted to use remote sensing for inventory and monitoring of Crown grazing lands under their jurisdiction. The Renewable Resources (Wildlife) agency, on the other hand, was interested in inventory and monitoring of wildlife habitat on public lands.

4. EXECUTION OF 1976 PILOT PROGRAMS

The actual execution of the three 1976 pilot projects is discussed under the four stages of the program (program planning, data acquisition, training and interpretation, and evaluation).

Program Planning Stage (July 1976)

In this important stage all of the decisions regarding objectives, choice of a study area (see Figure 1 for locations), remote sensing and ground survey data acquisition, and levels of participation are made. Although a period of two months had originally been proposed for this stage (i.e. beginning about April 1976), holdups delayed authorization until July, almost halfway through the grazing season. This unfortunately shortened the planning stage of the pilot projects to one or two weeks, since the data acquisition had to be completed by the first week of August at the very latest, and eliminated early season remote sensing. For the Alberta Forest Service, the pilot program was easily adapted to their existing summer field program; choosing a suitable study area and carrying out the ground surveys were relatively easily accomplished. The Alberta Lands Division was also relatively accommodating of this pilot project, although it required choosing a new study area and adjustment of summer field programs. The Manitoba group suffered most because of this short planning stage. The Agriculture personnel are still in the process of developing their range management program, which made designing a remote sensing program to complement current and proposed activities more complicated and time consuming. Generally unfamiliar with remote sensing and its application to range management, the Agriculture group required more time to carefully consider their objectives, but unfortunately the data acquisition could not be delayed and required rapid decisions.

Data Acquisition Stage (July - October 1976)

Because of the lateness of the season and the necessity of obtaining the remote sensing imagery quickly and correctly, INTERA ordered the Landsat imagery and obtained the FCIR photographs using their own aircraft and an RC-8 camera (loaned by the Canada Centre for Remote Sensing). The ground data collection was varied to suit the objectives of each pilot program but included species inventory, assessment of range conditions and clipping for productivity estimation (Table 1). In Manitoba, where they had very limited experience in ground survey methods normally used for range management, INTERA sent a range biologist, wildlife ecologist and a remote sensing specialist for the ground surveys, to assist in collecting ground information for the remote sensing. In the two Alberta projects, where range management field programs are already well established, only minor changes and additions were necessary and most of the ground work was carried out by agency personnel and their summer field staff, counselled by INTERA.

Training and Interpretation Stage (September 1976 to January 1977)

INTERA's approach to the training of the participants was to present a general overview of remote sensing and detailed material on the interaction of radiation and the target (mostly vegetation), false colour infrared film characteristics and Landsat imagery, and to provide hands-on experience with the remote sensing imagery obtained for each agency's study area as well as all the interpretation equipment. In fact, the training program was delayed in all three cases until the remote sensing imagery for the study area was available, so that it could be used as an integral part of the training. This proved to be a good approach, as it related the remote sensing theory to actual hands-on practice with photographs of a familiar area. Each participant then was to interpret the remote sensing imagery (with assistance as required from INTERA) in order to evaluate potential uses and applications to his agency's field of interest and objectives. To allow adequate time to study the imagery and formulate conclusions, regular field and office schedules had to be rearranged in most cases.

In the interpretation of the remote sensing imagery, emphasis was placed on basic techniques, primarily visual analysis using hand lenses and stereoscopes. Such easily obtained equipment can be used in future operational work right in the agency offices, a matter of practical importance. Good use was also made of a multispectral viewer for the Landsat imagery analysis in the case of the Alberta Lands Division pilot project (a densitometer was also used for this project). The participants appreciated this practical side to the pilot project, as their limited budgets do not easily allow for purchase of extra equipment.

By the end of the time allowed for interpretation (end of January) most participants felt at ease with the remote sensing imagery and wished to continue with the interpretation, since more information could be derived from the imagery and checked in the field during the next grazing season. Thus, although reports were produced for each of the agencies, further work will be done in most cases and more conclusive results attained. After the 1977 field checking, each interpreter will have more confidence in his ability, and will be better able to interpret and evaluate remote sensing applications in his range management program.

Every participant in the three projects, amazed at the resolution, ground detail and overall quality of the FCIR transparencies, felt that they were well worth the extra cost over standard panchromatic prints. Almost all agreed that the most useful photo scale for their work was a medium scale of about 1:20,000. The large scale photographs (1:2000) contained much more detail than they needed or wanted (this was confusing), and for two of the projects, the small scale (1:46,000) photographs were not detailed enough. This points out the necessity in a program of this type of suiting the photo scale not only to the data need, but also to the experience of the interpreter. In the case of this program, where almost every participant was new to the task of interpreting FCIR photo-

graphs, a scale which shows recognizable and familiar ground detail will produce the best results. As their experience in interpretation increases, then smaller scales (for inventory and monitoring at lower costs and with increased areal coverage) and larger scales (to solve more detailed problems) can be utilized effectively. It is important in the initial stages of a program such as this to minimize logistical and practical problems so that the focus is on interpretation. Choice of a photo scale from which maps showing meaningful units can be made, solves one of these important practical problems.

Evaluation Stage (February 1977)

The evaluation of the pilot projects was carried out in February 1977 (in order to meet contract deadlines), and the results of the remote sensing interpretation were considered preliminary since more work is yet to be done. Nevertheless, evaluation of the three pilot projects showed that each was successful in terms of its objectives to a different degree. Based on final meetings with the participants, material written by them on the pilot project, questionnaires (prepared by INTERA to obtain specific answers on project details from all participants), and INTERA's observations during the course of the pilot projects, the agency reports were prepared (see Reference Section).

Table 2 presents a summary of the results of the pilot programs for the four range management agencies in terms of areas of jurisdiction, current programs, objectives for use of remote sensing and future operational work using remote sensing. The objectives of the Alberta Forest Service pilot project were to use remote sensing to identify and map range types and range condition, and to use this information to modify the system of range use through changes in grazing allotment management plans. Through interpretation of the remote sensing imagery, they were able to improve on the quality and quantity of the data for mapping obtained by means of intensive ground surveys. Thus, they were satisfied with their results, and plan immediate implementation of remote sensing into their operational range management program. In future, they will save on man-time in the field and double their annual area of coverage of previous years under their current budget; this will improve both the frequency of rangeland monitoring and the data base upon which management decisions are made. This pilot program may thus be considered a success.

The Alberta Lands Division wanted to use remote sensing for evaluation of range condition, not through vegetation inventory, but rather through estimation of productivity (biomass). Their results were positive in that they were able to assess range condition, utilization and productivity at varying levels of detail from FCIR photography, from Landsat imagery, and from 35mm colour infrared slides. They identified operational uses for each of these remote sensing tools, and the means of implementing each into their operational program, depending on budget and available man-time. However, they also identified a number of problems which they feel require further investigation before remote sensing can fill all of the proposed operational niches, and they plan to continue with such investigations. Using the remote sensing techniques tested in the pilot program, they will be able to improve the monitoring capability of the agency both in frequency and in quality and quantity of data on which to base management decisions.

The Agriculture-Crown Lands agency in Manitoba wanted to identify carrying capacities through inventory of vegetation types and range condition, so that the remote sensing could be applied to their five-year inventory program. They did not carry their investigations quite to this point; however, they were successful in developing a preliminary legend for their inventory, and in mapping vegetation and range conditions using this legend. They are planning to refine the legend for their range inventory program and to further develop their interpretation abilities. They consider this pilot program to be successful in that they learned ground survey techniques, were made aware of the applications of remote sensing to range management programs, and developed interpretation skills. The Manitoba Wildlife group wanted to utilize remote sensing for inventory and assessment of three main types of wildlife habitat (that of white-

tailed deer, grouse, and waterfowl). They were successful at only one of these (assessment of waterfowl habitat) and plan to utilize FCIR photography for this purpose in their operational management programs next year, while continuing evaluation of the other two.

5. SUMMARY AND CONCLUSIONS

The results of these three 1976 pilot projects have confirmed the original assumption that remote sensing can play an effective role in operational range management programs in western Canada. Remote sensing tools can be implemented within the limits of present budgets, and can still provide a more detailed and efficient data base for management decisions than other methods. Investigations into the application of remote sensing to range management must still be continued, however, if not by the range management agencies themselves, then by other investigators, as the problems of imagery interpretation and methodology have not yet all been solved.

Detailed recommendations for the implementation of remote sensing into the operational range management programs of each agency made in the final report on the project (INTERA, 1977) are summarized in Table 2. Their positive results indicate that other range management agencies in western Canada should become involved in such work. Most of the involved agencies were satisfied that they can improve their management programs through implementation of remote sensing without major budgetary increases (which seems to be one main reason for not getting involved with remote sensing in the past). By making manpower changes, and lightening the field work load, an agency can allow for the costs of remote sensing data acquisition. Small budgetary increases, if granted, then can only serve to further improve the management program by allowing even more frequent inventory and monitoring of the area under their jurisdiction, an objective of every range management agency. Before becoming involved in a pilot project of this type, however, they should have an established operational program and clearly defined objectives for the implementation of remote sensing. Otherwise, the pilot project is not utilized efficiently and the objectives are not realized to their full extent.

The importance of this pilot program lies not only in the individual results obtained from the remote sensing imagery by each range manager/interpreter, since these are relatively basic and probably overly obvious to anyone involved in remote sensing research in rangeland management, but also in the success of the program in transferring remote sensing technology from research to operational management programs. Not only in range management, but in many other fields, remote sensing can be successfully implemented into operational programs; facilitated with respect to time and efficiency by making use of an "expert" (whether a consultant, a government scientist or a knowledgeable person from the range agency) to guide the agency, this pilot program approach provides a mechanism for such a transfer.

ACKNOWLEDGMENT

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TABLE 1
SUMMARY OF 1976 AGENCY PILOT PROGRAMS

	<u>ALBERTA FOREST SERVICE</u>	<u>ALBERTA LANDS DIVISION</u>	<u>MANITOBA</u>
<u>Study Area</u>	Todd Creek-Rock Connolly (2 grazing allotments - 84 km ²)	Rowley-Jakes Butte (2 grazing association leases - 50 km ²)	Narcisse (200 km ²)
<u>Range Type</u>	<u>Foothills</u> 1. Grasslands (<u>Festuca scabrella</u> , <u>Danthonia parryi</u>) 2. Browse (<u>Salix</u> spp., <u>Amelanchier alnifolia</u>) 3. Conifers (<u>Pinus</u> spp., <u>Picea glauca</u> , <u>Pseudotsuga menziesii</u>) 4. Deciduous (<u>Populus tremuloides</u>)	<u>Midgrass Prairie</u> (<u>Festuca scabrella</u> , <u>Stipa comata</u> , <u>Bouteloua gracilis</u> , <u>Agropyron</u> spp.)	<u>Parkland</u> 1. Grassland (<u>Stipa comata</u> , <u>Danthonia</u> , <u>Poa</u> spp.) 2. Wooded areas (<u>Popu- lus tremuloides</u> , <u>Quercus</u> , <u>Picea glauca</u> , <u>Cornus stolonifera</u>)
<u>Airborne Remote Sensing</u>			
<u>Type</u>	FCIR Photographs 23 cm roll trans- parencies	FCIR photographs 23 cm roll trans- parencies	FCIR Photographs 23 cm roll trans- parencies
<u>Scales</u>	1:40,000 1:16,000 1:2,000	1:46,000 1:20,000 1:2,000	1:46,000 1:24,000 1:2,000
<u>Dates</u>	July 26, 1976 October 1, 1976	July 23, 1976 August 13, 1976	August 3, 1976
<u>Landsat Imagery</u>			
<u>Bands</u>	5,7	5,7	----
<u>Dates</u>	May 9 & 10, 1976 July 2 & 20, 1976 Sept. 13, 1976	July 2, 1976	----
<u>Other</u>	-----	35 mm colour and colour IR slides	----
<u>Ground Data</u>	1. range types (species) 2. range condition 3. range developments 4. forage production	1. forage production from 80 sample sites 2. general descrip- tion of range	1. range types (species) 2. range condition 3. range developments 4. forage production 5. wildlife habitat assessment
<u>Method of Interpretation (Major)</u>	1. Mirror stereoscope 2. Hand Lens 3. Multispectral viewer (Landsat)	1. Mirror stereoscope 2. Hand Lens 3. Multispectral viewer 4. Densitometer	1. Mirror stereoscope 2. Interpretoscope

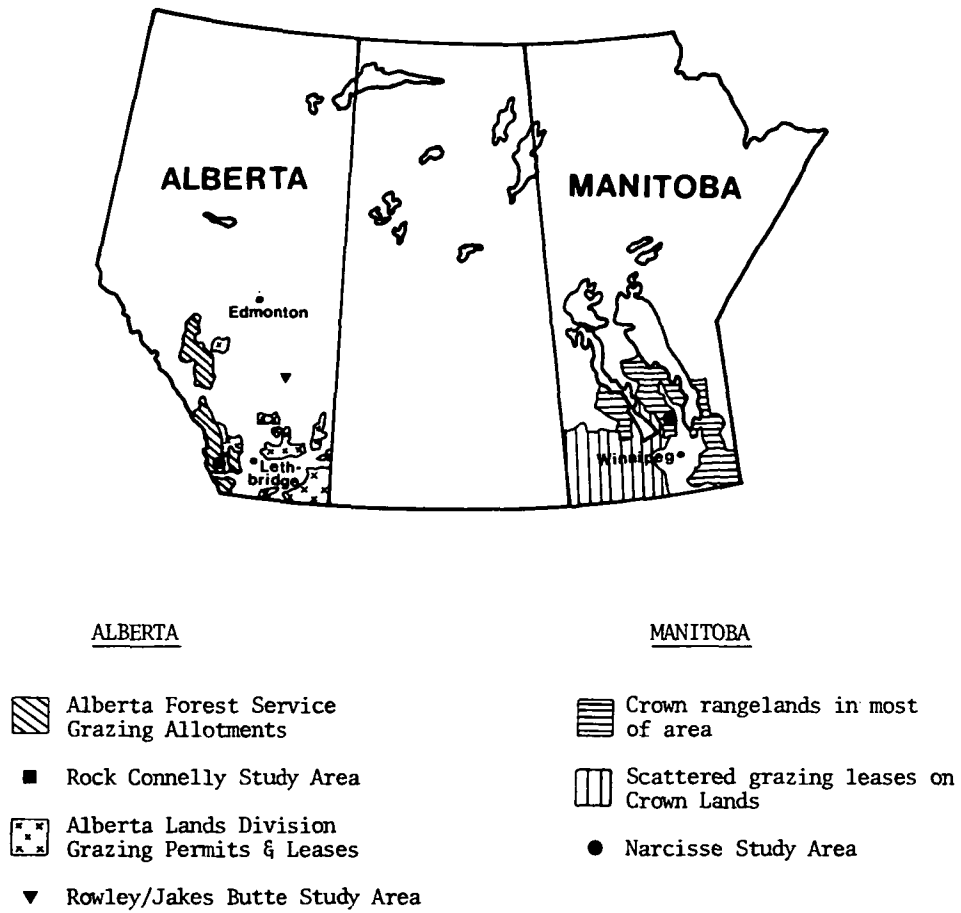
TABLE 2
SUMMARY OF OPERATIONAL REMOTE SENSING OF
RANGELAND PROGRAMS IN ALBERTA AND MANITOBA

	ALBERTA FOREST SERVICE	ALBERTA LANDS DIVISION			MANITOBA	
					AGRICULTURE	WILDLIFE
AREA OF JURISDICTION	365,000 ha. (3650 square km) in Forest Reserve (plus northern Alberta Green area)	2,430,000 ha. (24,300 square km) in S. and Central Alberta			810,000 ha. (8100 sq. km)	Not available
TYPE OF RANGELAND	Mainly foothills grasslands and bushlands range (plus northern boreal areas)	short- and mid-grass prairie			grasslands to parklands	grasslands, parklands and boreal forest, and wetlands
CURRENT MANAGEMENT PROGRAM	regular inventory (15 year interval) for update of management plans for 90 grazing allotments	monitoring range productivity and condition on grazing leases.			beginning inventory of all leases to establish carrying capacity over 5-year period	evaluation of wildlife habitat especially for deer, grouse and waterfowl
OBJECTIVES FOR USE OF REMOTE SENSING	reduce inventory interval thru remote sensing interp. for better data base (range type, condition, trend, utilization)	estimation of biomass (productivity) on grazing leases and permits			inventory of grazing leases (species assoc., condition, utilization)	inventory and evaluation of waterfowl habitat, to be used in planning and development
REMOTE SENSING FOR OPERATIONAL WORK						
TYPE(S)	FCIR photography	Landsat FCIR photog. 35mm			FCIR photography	FCIR photography
TIME OF YEAR	September	all season	June (end)	June July Sept.	spring, July	July
SCALE	1:16,000	-	1:46,000	1:20,000	1:20,000	1:10,000 (approx.)
METHOD OF INTER- PRETATION	visual (hand lens & stereoscope)	multi-spec- tral viewer	visual (stereo- scope)	visual (hand lens)	visual (stereo- scope)	visual (stereoscope)

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FIGURE 1
 RANGELANDS IN ALBERTA AND MANITOBA
 AND LOCATION OF STUDY AREAS FOR 1976 PILOT PROJECTS



AN APPLICATION OF LANDSAT DIGITAL TECHNOLOGY TO FOREST FIRE FUEL TYPE MAPPING

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ABSTRACT

Economic limitations prevent the mapping over large areas of forest fire fuel types using conventional forestry methods. The information contained in such maps would be a valuable tool for assisting in initial attack planning, presuppression planning and fire growth modelling. During the past several years, the Forest Fire Research Institute with assistance from the Canadian Centre for Remote Sensing, has examined the role of digital classification and enhancement methods for producing general forest cover classifications suitable as fuel maps. A Taylor enhancement (Dr. M.M. Taylor, Defence and Civil Institute of Environmental Medicine, Department of National Defence, Downsview, Ontario) was produced for an 8 million hectare fire control region showing water, muskeg, coniferous, deciduous and mixed stands, new clearcut logging, burned areas, regeneration areas, nonforested areas and large forest roads. Use of this map by fire control personnel has already demonstrated its usefulness for initial attack decision making.

Recent work has dealt with temporal overlays and has shown the merits of this approach. Future work is aimed at constructing a digital data base containing geometrically corrected temporal classifications for a large area. When completed, this data base should provide timely information to fire control decision makers and to a fire growth model.

FOREST FIRE FUEL MAPS

The type of forest fuel in which a fire burns is an important factor in determining the fire's rate-of-spread and difficulty of control. As long ago as 40 years, maps showing general forest cover types of fairly uniform fire behaviour characteristics were produced for small areas of the United States and Canada. These maps were made using conventional forestry photography and map-making procedures. However, high labor costs associated with their initial construction and later revisions, forced the abandonment of this approach by the late 1940's.

As timber inventory maps became available, attempts were made to group types into broad fire behaviour classes. Approximately one man-day was required to color a 100 square kilometer timber map. This high cost, the difficulty of keeping maps current, and the lack of complete timber map coverage has discouraged the general use of this approach.

Since the successful operation of the Landsat resource survey satellite, a whole new technology for mapping general forest fuel types has emerged. This technology offers the potential for inexpensive maps over huge areas showing previously economically unobtainable information necessary for a modern fire control operation. In 1974, the Forest Fire Research Institute in conjunction with the Canadian Centre for Remote Sensing (CCRS) began to investigate the capabilities and limitations of some of the various digital processing methods appropriate for forest fire fuel mapping. This paper briefly summarizes our progress, findings, and proposed future work.

INITIAL TRIALS

A test area 250 square kilometers in size was located 250 kilometers northwest of Ottawa in the Province of Quebec. The test area included a mixture of forest stands characteristic of both the northern Boreal and Great Lakes forest types. Conventional forestry aerial photography, low-level 70 mm and oblique photography, timber type maps, and ground checks were used to verify our results. Supervised maximum likelihood classification, unsupervised classification, and digital enhancement methods were used. All data processing and image displaying were done on the CCRS's Digital DEC-10 computer and Bendix Multispectral Analyzer Display system.

Early experience was gained using supervised maximum likelihood classification. Water, new clearcut logging areas and pure deciduous and coniferous stands could be consistently classified over large areas provided suitable care was taken to identify and locate training areas. Because a large proportion of the test area consisted of all degrees of deciduous-coniferous mixtures, instabilities in the classification were encountered with this approach. Small changes in the training area locations and sizes in transition forest types resulted in significantly different classifications. Unsupervised classification, although it required as much ground truth and operator time as supervised classification, seemed to produce results closer to those shown on the original timber type map. Over large areas the following could be consistently classified: water (small water sources for fire pumps are very important), pure deciduous, coniferous and mixed stands, muskeg, nonforest, and newly cut logging slash areas.

Although in local areas broad species and age class groups could be separated when they occurred in homogeneous stands, it seems safe to conclude that, at the moment, coniferous age class, density and species seem hopelessly confounded over large areas. At the time of these experiments neither classification method produced geometrically correct output or the all-important forest road detail necessary for rapid access to remote fires.

The Taylor digital enhancement method was tried next. From the fire control field personnel's point of view, this approach represented a significant improvement over previous classification results. Enough geometric correction was carried out in the enhancement program to overcome previous field personnel complaints. The users felt that enhancement output closely resembled aerial photographs, in that, transition forest areas could be clearly seen. In addition to those types consistently identified by classification methods, the enhancements showed a broad measure of the degree of revegetation on clearcut logging and burned areas plus significantly improved road detail.

Perhaps more important, enhancement output to the field personnel resembled a map in which considerable human interpretation was still required. Their experience was essential in interpreting the imagery. Classification output lacked credibility, partially because the field personnel were not part of the interpretation "loop". This same problem arises frequently with conventional aerial photography and the corresponding timber maps produced from them. Recognizing the complexity of the forest and the classification difficulty, users frequently insist on using the original photography in conjunction with the timber map.

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CONSTRUCTION OF A FUEL MAP

Based on the quality of results obtained in the test area using the enhancement method and the acceptance of these by field personnel, it was decided to produce a demonstration map of a large area. An 8 million hectare area protected by the Societe de Conservation de l'Outaouais (SCO) was selected. A map consisting of 120, 20 x 25 cm photographs of enhanced images at a scale of 1.25 km/cm spanning 5 Landsat frames was constructed and indexed in terms of the SCO's fire location grid structure. This grid, plus the abundance of small lakes in the region, made the location of any fire in the region a simple task on the Landsat enhancement imagery.

Approximately 5 man-days and several computer hours were spent in reaching the best overall set of enhancement parameters. Compromises had to be reached between the degree of coniferous and mixed-wood forest separation and the amount of road and clearcut detail. Another several man-days and about 3 hours of computer time were required to enhance the 120 images. A conventional 35 mm camera and film were used to photograph the display screen. These photographs were later enlarged to the final output size.

The most difficult task in producing the map was the search for and selection of suitable imagery. Experience had shown that only imagery during July and August should be used in eastern Canada. It is impossible to obtain early spring imagery in southwestern Quebec before the deciduous foliage appears without some snow on the ground or ice in the lakes. Later in the spring - say late May or early June, phenological differences between the time of leafing and the coloring of deciduous species coupled with terrain and micro-climate influences result in confusion as to deciduous identification. The same confusion is present in September and October.

Winter imagery enables excellent coniferous-deciduous separation and presents a great deal of coniferous density and age class information. However, there is total confusion in the identification of nonforest areas, lakes and newly clearcut slash areas. Roads only show well when they run through coniferous forests.

Cloud and haze obstruction of imagery is a major problem in eastern Canada. During July and August the chance of obtaining a single nearly cloud-free frame is surprisingly low. For example, all frames in the Outaouais region during the summer of 1976 contained at least 50 per cent haze or clouds. Imagery from the summers of 1974 and 1975 were used to construct the SCO fuel map.

Atmospheric haze presented a more serious problem. Subtle changes in enhancement colors, caused by increasing and decreasing haze levels, could gradually take place across a frame eventually causing the user to misinterpret an area. Only after careful visual scrutiny of bands 4 and 5 in raw form was this problem reduced.

Although the Taylor enhancement color shadings varied from frame to frame for the same general forest cover type, the range of variation was small and presented no problem to the field personnel. Several weeks of personal comparisons, by fire control users, of the enhancement map to existing timber maps, aerial photography, personal knowledge of specific areas and field checks led to the confidence necessary for their general acceptance and use.

Field experience with the Landsat fuel map last summer immediately showed its value. One particular example stands out. A fire was reported and a conventional dispatch of ground personnel ordinarily would have followed. A check with the fuel map showed a large and very dangerous logging slash situation downwind from the fire. An immediate dispatch of water bombers and helicopters stopped the fire at the edge of the slash area. The savings were estimated to be between 20,000 and 50,000 dollars. The cost of the Landsat map was probably about 3,000 dollars.

We have not yet had the opportunity to test the usefulness of the fuel map for large fire suppression when conventional reconnaissance methods frequently fail because of heavy smoke.

TEMPORAL OVERLAY EXPERIENCE

Work has continued on this project aimed at improving our ability to map fuel types and other information relevant to fire control. Specifically, we have worked at improving our coniferous-mixedwood separation, forest blowdown mapping, access road detail, clearcut and burn regeneration aging, insect defoliation and geometric correction.

With much assistance from CCRS, we have been able to overlay sections of different frames, as large as 1/2 million hectares, with a maximum error of about 1 pixel. Overlays have been made using winter bands onto summer bands and winter bands onto winter bands. Each Taylor enhancement of an overlay combination resulted in new information. Some combinations were much better than others. Of the few combinations tried to date out of the many possible, the most informative has been band 5 of winter overlaid onto band 5 of summer with the remaining summer bands left unchanged. An enhancement of this combination resulted in road detail better than previously obtained, separations of the general cover types into such distinct color groupings that the output resembled a classification, plus three fairly distinct clearcut logging regeneration age classes. In addition, the area logged during the time between the two satellite passes was clearly identified as a unique tone both by a 3-color display of "raw" data and by the Taylor enhancement.

In eastern Canada wind storms destroy significant areas of coniferous forest. The large fuel quantities remaining in these areas present serious problems to fire control. It is most difficult, if not impossible, to map these areas either on summer or winter imagery. On summer imagery blowdown areas can resemble regeneration areas and on winter imagery they cannot be separated from deciduous types. Experiments with temporal overlays showed that enhancements of winter-winter overlays clearly identified blowdown areas. Here a winter frame made previous to the blowdown was overlaid onto a winter frame made after the blowdown (i.e. band 4 onto band 7). Although we have not tried it, this same technique seems to offer the greatest potential for mapping areas of severe defoliation of conifers by insects. We have already seen that such defoliation can be identified on winter enhancements.

LANDSAT FUEL DATA BASE

Temporal overlaying currently is a difficult, time-consuming process and consequently has not seen much experimentation. We have done enough of it to recognize its potential and also to identify some of the problems associated with it. Most serious of the problems encountered to date is the apparent instability of the information content for a given overlay combination in widely separated locations. For example, the most informative winter-summer combination in our test area was not the best combination several hundred kilometers away. In fact, the Taylor enhancement resulted in totally different color schemes in the two areas even though the band combinations were the same. Clearly, radiometric variations, haze and phenological differences are much more important in temporal overlaying.

The ability to automatically identify changes over large areas using temporal overlays must be the key to the Landsat program's future. We already have demonstrated two feasible and useful change detection functions for fire control - namely clearcut and blowdown monitoring. Our future work is aimed at the construction of a geometrically correct digital data base, covering the 8 million hectare area of the SCO fire region, in which classifications of many registered frames can be stored. Our first step toward this goal has been to outline the general data base structure and to geometrically modify a 2.5 million hectare area of summer data to match a Universal Transverse Mercator grid map using 1/2 hectare, square data cells. Future overlay frames will be modified using the same base and hopefully will be registered with sufficient accuracy for fire control purposes. The next step, and the one now underway, is to classify this data into the broad fuel categories previously mentioned. This will be a two-step process using an unsupervised classifier and stratified data. Step one will be aimed at classifying forest cover types using data within the limits of their spectral ranges of the forest fuel types. Step two will be aimed at producing improved road and clearcut information. To do this,

the unsupervised classifier will be restricted to work with only the data with reflectances above 14 in bands 4 and 5. Results from the two-step process will be merged within the data base.

Once the SCO region has been completed using summer data, the process will then be repeated using winter data. The data base will have the potential to store the results and the dates of up to 4 temporally different classifications for each 1/2 hectare cell. In addition, a scheme is being developed to identify and place a reliability measure on the most likely fuel type of each data cell. The reliability measure will be based on permanent ground truth plots, spatial information and logical temporal and phenological possibilities.

The data base itself will be contained on a series of magnetic tapes and used on a Digital PDP-11 T34 mini-computer. Special computer programs will be written to be used by fire control personnel in their daily decision making process. These programs will extract from the data base the distance from a given fire location to the nearest water source for fire pumps, the nearest road for ground access, the nearest long lake for water bomber pickup, the distance and direction of logging slash areas and a summary of fuel types within a given range of the fire. This information will be useful in deciding the type and strength of initial attack on the fire. FFRI has developed a contagion fire growth model that can predict future perimeter locations of a large fire, given weather forecasts, fuel moisture estimates and fuel types on a two hectare grid. The data base will be used to furnish the fuel data to this model.

CONCLUSION

The fire control application described in this report seems ideally matched to Landsat's capabilities. We have demonstrated that useful forest fuel maps can be produced for large areas for low costs using existing digital processing equipment and software. Enough experimentation using temporal overlays has been carried out to demonstrate their potential in increasing the information extracted from Landsat data. Presently we are attempting to construct a digital data base to be used within the operational fire environment to assist in initial attack decision making and fire growth modelling. This same data base should provide change detection information such as locations of new roads and logging slash areas, important to long-term fire control planning.

LANDSAT IMAGE INTERPRETATION AIDS

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ABSTRACT

In the Large Area Crop Inventory Experiment, image interpretation aids were produced to assist in selecting and/or identifying representative samples of signatures in a given Landsat scene. The three methods employed are based on clustering techniques, information extraction, and aggregation of like spectral information on a two-dimensional spectral plot.

1. INTRODUCTION

Image interpretation is an important method for acquiring training data for classification of Landsat images in the Large Area Crop Inventory Experiment (LACIE [1]). Interpreting a scene for classification requires that training fields containing statistically representative samples of all spectral signatures in the given scene be selected and correctly labeled. This becomes especially difficult when multiple passes over a scene are to be interpreted. The variation of the spectral signatures, in a multitemporal sense, makes it difficult to select and identify all of the variety of signatures in a scene. To address these problems, three image interpretation aids were developed.

The first and the second image interpretation aids were obtained by applying nonsupervised pattern recognition techniques (clustering) and data compression. The clustering method identifies the inherent classes in the scene. Color film is generated from the cluster image, with each cluster having a distinct color - the color corresponding to the value of the cluster mean [2]. In interpreting multipass data, a principal component (PCOMP) transformation technique is applied to the cluster image. This compresses or summarizes the multitemporal spectral variation of the scene into a three-dimensional image which can be displayed as a color image. In order for the analyst to view the structure of the Landsat data in spectral space, a two-dimensional spectral plot of the data was developed as the third aid. The spectral plot [2] takes advantage of the inherent two-dimensionality of Landsat data [3]. The plots are constructed to assist in relating picture elements (pixels) in the scene to their locations on the spectral plot.

2. CLUSTER IMAGE

A cluster image is generated first by clustering the data in the scene and then by replacing each data sample according to the cluster mean to which it belongs. Color infrared (CIR) film of the cluster image can be generated by a production film converter (PFC). One of the main features of the cluster image is that two spectrally similar clusters are shown by the film product to have similar colors. This feature easily could be lost when an arbitrary color assignment is used to generate a film product from the one-dimensional cluster map. A CIR film product of the cluster image normally is generated using the same gain and bias as that used to produce the original CIR image. This results in a CIR film product of the cluster image that resembles the standard CIR film product.

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A color key of the clusters is generated also by assigning a square of 100 samples (pixels) to each cluster. Each pixel in the square is equal to the cluster mean it represents. The color keys are then ordered according to the Kauth greenness number [3].

It was discovered from observing cluster images on CIR film that they can be used as aids in defining spectral classes and helping to standardize the image interpretation procedure. In addition, an increase in the contrast of adjacent fields is apparent, which assists in the delineation of training fields.

3. PCOMP CLUSTER IMAGE

A PCOMP cluster image of a scene is generated by applying the PCOMP transformation to the cluster image described in section 2. Ready and Wintz [4] have shown that the PCOMP transformation applied to airborne and satellite-gathered multispectral data is very useful for information extraction, since the first few PCOMP images contain essentially all the information present in the original spectral bands. Additional analyses of PCOMP transformed Landsat data are available [5].

The PCOMP transformation is

$$\underline{Y} = \underline{M}\underline{X} \quad (1)$$

where

$\underline{X}$ = a vector of n spectral intensities associated with each pixel.

M = an n -by- n unitary matrix derived from the mixture covariance matrix Σ_X of the spectral bands such that the rows of M are the normalized eigenvectors of Σ_X .

$\underline{Y}$ = a vector of n PCOMP's.

The covariance matrix of the PCOMP transformed data then becomes

$$\Sigma_Y = M\Sigma_X M^T = \begin{bmatrix} \lambda_1 & & & 0 \\ & \lambda_2 & & \\ & & \ddots & \\ 0 & & & \lambda_n \end{bmatrix} \quad (2)$$

where $\lambda_1, \lambda_2, \dots, \lambda_n$ (the variances of the PCOMP's) are the eigenvalues of Σ_X ordered so that $\lambda_1 > \lambda_2 > \dots > \lambda_n$ and M^T is the transpose of M .

Since M is a unitary matrix, the PCOMP transformation preserves the total data variance; i.e.,

$$\sum_{i=1}^n \sigma_{x_i}^2 = \sum_{i=1}^n \lambda_i \quad (3)$$

where the values for $\sigma_{x_i}^2$ are the variances of the original spectral bands. Note that in the PCOMP transformation most of the data variance is concentrated in the first few PCOMP's. It was observed that, for Landsat data in four channels, $\lambda_1 + \lambda_2$ contained approximately 96 percent of the total data variance. In eight channels of Landsat data, $\lambda_1 + \lambda_2 + \lambda_3$ contained approximately 91 percent of the total data variance. For 16-channel Landsat data, $\lambda_1 + \lambda_2 + \lambda_3$ contained approximately 82 percent of the total data variance. The interest in the first three PCOMP's of Landsat data arises from processing color film products. A PFC generating a color product of Landsat data uses three channels, with each channel assigned to the blue, green, or red color film gun. Since the first three PCOMP's contain most of the data variance, the PCOMP transformation, which uses the first three PCOMP's, seems to be a good method of reducing multitemporal data.

Once the PCOMP transformation is applied to both the cluster image and the color keys, the transformed data are rescaled to lie between 0 and 255 to allow storage of the image in a standard image format.

4. SPECTRAL PLOT

A spectral plot of a Landsat scene is a graph of one channel of the data versus that of another. The spectral plot relates the image space (i.e., the spatial domain) of the PFC product to the spectral space of the classifier. A schematic diagram showing the relationship between image space and spectral space is shown in figure 1. The spectral plot uses the inherent two-dimensionality of Landsat data where most of the spectral class separability exists [3]. For example, overlaying the spectral plot of training field means over the spectral plot of the scene provides a quick view of missing signatures and of the corrections to subclass assignments.

The axes used for generating a spectral plot may be two selected Landsat channels or two linear combinations of channels; i.e.,

$$\underline{Z} = \underline{B}\underline{X} + \underline{e} \quad (4)$$

where

$\underline{B}$ = a two-by-n transformation matrix of rank 2.

$\underline{e}$ = a two-by-one bias vector.

$\underline{Z}$ = a two-by-one vector of the channels to be plotted.

The transformation matrix $\underline{B}$ might be formed from the first two rows of the Kauth transformation, the first two rows of $\underline{M}$ in equation (1), or from a linear-combination feature-selection algorithm [6]. If $\underline{B}$ is obtained from the Kauth transformation, then the dimension of the data n must be four since the Kauth transformation is a four-by-four matrix.

A color-coded spectral plot contains the locations of the pixels and the channels to be used for coloring them on the spectral plot. The location of each pixel on the spectral plot is computed using the radiance values (or linear combinations of radiance values) of the pixel. Multiple pixel occurrences at the same location on the spectral plot are shown to be the color of the pixel corresponding to the first occurrence. To illustrate what is meant by a color-coded spectral plot, assume that a given pixel on the Landsat image has radiance values of 28, 30, and 50 on channels 1, 2, and 4, respectively, as shown in figure 2. Also, let channel 4 be plotted versus channel 2. The color-coded spectral plot is created by assigning the values of 28, 30, and 50, respectively, to the point (30,50) on channels 1, 2, and 3 of the spectral image. By maintaining the same gains and biases, the color-coded spectral image can be displayed in the same color as the original Landsat image. With such a spectral plot, the full effect of color-shaded aggregation can be observed.

The color of the pixel on the spectral plot is optional. It can be colored according to its original radiance value or the mean of the class, cluster, or field from which it was extracted. Naturally, the location of the pixel on the spectral plot can be displayed in the PCOMP colors.

Color-coded spectral plots can be used to observe the partitioning of spectral space imposed by clustering or by maximum likelihood classification. It can be used also to view the spectral locations of training samples. A partition of the two-dimensional spectral space by the maximum likelihood classification rule is depicted on the color-coded spectral plot by assigning a color to the pixel on the plot according to the mean of the subclass to which it was classified. A change in the color or its intensity on such a plot determines the maximum likelihood decision boundary.

When multiregistered Landsat images are available over a scene, the location of the pixels to be plotted can be selected from two channels of one pass, whereas another pass would be used for color definition. Such a color-coded spectral plot

is especially useful for the analysis of multitemporal Landsat data. Through spatial correlation of this color-coded spectral plot and the Landsat image from which the plotting axes are selected, areas where temporal change because of factors such as growth, disease, severe weather conditions, and harvest can be delineated.

A typical application of the color-coded spectral plot, which is currently being considered for applications in the LACIE, is to use the plot as an aid in labeling the training samples. This is done by providing a spatial correlation between the spectral plot and the original Landsat image.

5. CONCLUSION

To aid in interpreting the Landsat image, three color image display techniques were presented. These interpretation aids are the cluster image, the PCOMP cluster image, and the color-coded spectral plot. From the results of preliminary experimentation, the three displayed techniques have been shown to be useful in selecting training data from Landsat images. The developed interpretation aids are being considered for implementation in the LACIE.

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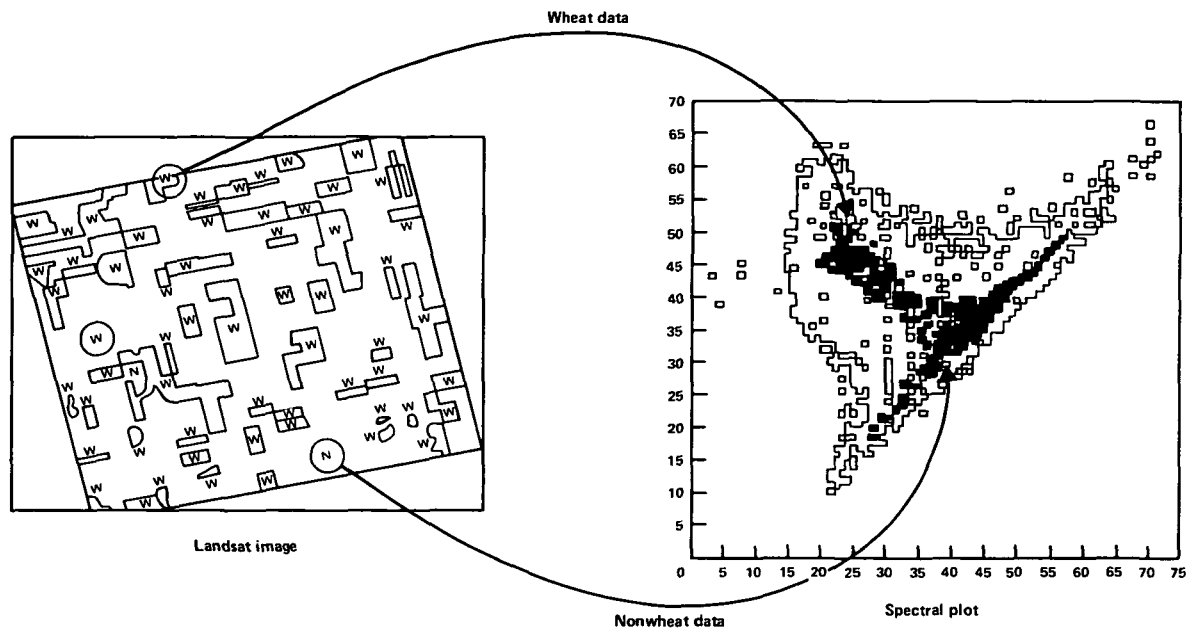


FIGURE 1. IMAGE AND SPECTRAL SPACE. A schematic diagram showing the relationship between image space and spectral space.

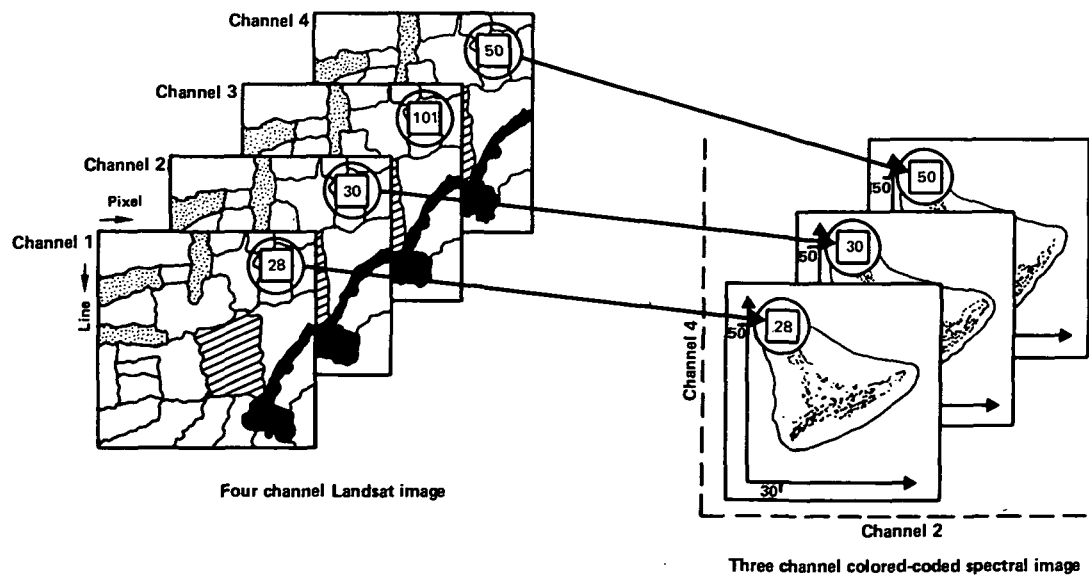


FIGURE 2. STRUCTURE OF COLOR-CODED SPECTRAL PLOT. A diagram showing how Landsat radiance values are plotted on the color-coded spectral image.

DIGITAL PROCESSING SYSTEM FOR DEVELOPING COUNTRIES

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ABSTRACT

Digital data processing systems have, until now, consisted either of expensive dedicated hardware systems or complex software packages. An effort was undertaken in Sri Lanka to perform simple digital processing tasks using pre-existing general purpose digital computers. An experimental software package, LIGMALS, was obtained and modified for this purpose. The resulting software permits basic processing tasks to be performed including level slicing, gray mapping and ratio processing. The experience gained in this project indicates a possible direction which may be used by other developing countries to obtain digital processing capabilities.

INTRODUCTION

As the field of remote sensing continues to advance, and major improvements are made in analysis techniques, it is becoming increasingly obvious that automated processing of digital data products is, for the most part, a necessary component in a balanced program of remote sensing imagery interpretation and utilization. When the user has available to him some of the expensive dedicated hardware systems or complex analysis software that have been designed in recent years, the processing of digital data products is a fairly straightforward task. However, when no such hardware or software is available, and no major funding can be obtained for the acquisition of these systems, the usual course of action is to delete automated processing from the interpretation scheme. This is often the case in developing countries. Very often when an attempt is made to develop "home grown" processing systems using available computer components and local scientists as the starting point, the lack of experience and the scarcity of printed instructions on how to proceed in the development of such a system prove an almost insurmountable stumbling block.

Such a problem was encountered in Sri Lanka, where a team from the Office of the Surveyor General was attempting to implement digital processing techniques for use with LANDSAT CCT's. This paper is a summary of the results of a project undertaken jointly by Sri Lanka and ERIM which was funded, in part, under a grant received from the U.S. Agency for International Development.

PROCEDURE

The major component of this project was to develop the capability of Digital Processing of LANDSAT Data (on CCT) through computer facilities available in Sri Lanka. Such available facilities were limited in computer capacity, to 48K of core memory. Other computer accessories were also limited to Card Reader, Card Punch, Line-Printer, Mag Tape Drive and Disc Drive facilities.

There were no facilities for interactive processing of data. We still do not have this facility. Hence we had to resort to the batch-mode execution of programs using a very small core memory capacity, available to the user.

This study commenced in the early part of May 1976. The computer facility used by the Survey Department up to this period was the ICL 1901, 24K capacity computer at the State Engineering Corporation. We had experience in executing programs for Geodetic computations and Photogrammetric Aero-triangulation at this facility. However, it was decided to conduct this investigation at the computer facility of the State Department of Census and Statistics, especially due to the great enthusiasm shown by the scientists there. Their computer facility consisted of an IBM 360, model 25, computer with 48K capacity. In the meantime, a study of the NASA publication "Generation and Physical Characteristics of the LANDSAT 1 and 2 MSS Computer Compatible tapes", was being conducted. No CCT was available at this stage. However, we wanted to obtain more information regarding the problem of reading and preprocessing a LANDSAT CCT. Up to this period a reference library on remote sensing was gradually developed. Reference to this literature revealed that none of the publications contained any information on such techniques. Though, all of them wrote at length on the significant achievements and results of tests etc., there were no descriptions of the actual techniques used. This was particularly lacking in the articles referring to computer processing.

A working group was formed within the Survey Department, consisting of personnel experienced in Photogrammetry, Scientific computer programming, Photo Laboratory Techniques and Photo-interpretation. We then wrote to various organizations and scientists involved in remote sensing and LANDSAT Digital Data Processing, seeking information on this subject. The replies received were not helpful. In fact, some expressed the opinion that LANDSAT CCT processing would not be possible on such small scale, general purpose computers of the type we have access to, in Sri Lanka. It was revealed that many organizations used special purpose, high capacity computers or extremely expensive general purpose computers of very high capacity with various display and inter-active capabilities.

The acquisition of such expensive hardware for our country could not be justified by any stretch of imagination, considering the limited number of frames required to cover the country, the limited frequency of coverage, the uncertainty of regular coverage due to cloud-cover and tape recorder capacity limitations on LANDSAT and our own foreign exchange limitations.

A further expansion of the working group was necessary to investigate this problem. Experts in computer systems analysis were co-opted into the group in a consultative capacity. During this period, we were informed by ERIM of the existence of an experimental digital processing package at the University of Michigan for use with LANDSAT CCT's on small scale computers. This processing package was named LIGMALS (Landsat Interactive Gray Map and Level Slicing system). Arrangements were made through ERIM to obtain a copy of this package.

We had the choice of only two LANDSAT frames which were suitable for investigation purposes. The first was frame ID 1234-04233 of North-East Sri Lanka acquired on 14 March 1973. The second was frame ID 2339-04151 of South-West Sri Lanka acquired on 27 December 1975. The first frame covered an area which has come under extensive development through the restoration of ancient irrigation works supplemented with additional irrigation through the diversion of Sri Lanka's largest river (Mahaweli) completed in January, 1976. The spatial distribution of large homogeneous tracts of rice cultivation and the irrigation pattern was clearly discernible in this LANDSAT image. But we were aware that from March 1973 onwards there were major changes in the development of this area mainly due to the diversion of the Mahaweli River. The use of this frame, 3 years after acquisition, would have resulted in serious difficulties of correlating ground truth with the LANDSAT data because we did not even have aerial photography of this area taken around the same season. On the other hand the second frame was

acquired in December 1975 and was somewhat more suitable for ground truth correlation, through the use of aerial photography and short field visits from Colombo. However, we were aware of the major problem of a very complicated spatial distribution of the data within this frame. This area is highly developed with homesteads mixed with coconut, rubber, small forest reserves and very narrow and spatially complicated pattern of rice fields following the drainage pattern. Due to lack of anything better, we were compelled to take up this frame for digital processing. The CCT of this frame was received in July 1976.

We consulted local computer experts in the University, IBM and the Department of Census and Statistics on how to access the data from the CCT. The consensus of their opinion was that at some stage or the other, we had to go down to a lower level language. Two persons were, therefore, sent for a two-month training course in Assembler Language conducted by the Sri Lanka Branch of IBM. In the meantime we received from ERIM, the LIGMALS software package. We started to decode and document this program and at the same time converting parts of this program package to suit our local computer system as regards language and batch-mode operation. With this package, combined with additional information [1,2] it was possible to build up a viable program for batch-mode operation in our system.

Due to the lack of visual display facilities the sections of the LIGMALS program necessitating video display, were omitted or modified. The original LIGMALS package was divided into five different stand alone programs for batch mode operation. There are:

- 1) REFORM - a program to reformat LANDSAT CCT's into an IBM FORTRAN compatible format.
- 2) RSET - a program to locate and extract a desired area to be processed for further investigations.
- 3) ALSET - a program to automatically define level set boundaries for use with the gray mapping routine.
- 4) PMAP - a program to generate a line printer gray map of an area utilizing either automatically or manually derived gray-level boundaries.
- 5) RATIO - a program to apply a ratio processing algorithm to data to obtain a new imagery channel of an area after performing appropriate path radiance corrections.

Because the programs we received were optimized for use on the University of Michigan computer system, which is a large time sharing system using multi-processing and virtual memory techniques, some sections of the program had to be extensively modified to be able to operate on the system in Sri Lanka. Additionally, an Assembler language input routine had to be written to accommodate EROS formatted CCT's which had been handled by system callable utility routines in the University of Michigan system environment.

DISCUSSION AND CONCLUSIONS

The work performed in this study has shown that it is possible for a developing country to obtain sufficient information to provide a starting point for a digital processing capability. Further, once the basic LIGMALS capabilities were implemented in Sri Lanka, local scientists had obtained sufficient experience with processing techniques to develop their own special purpose software without additional help from outside of their country.

Based on the experience gained in the Sri Lankan study, ERIM has produced LIGMALS/B which is a software system written totally in FORTRAN, and which is

designed to function in a small to medium sized computer system environment. Also, extensive diagnostic procedures have been developed for use when the package is installed, a feature we believe is necessary since many times minor problems may go unnoticed by scientists who are not yet used to the behavior of digital image processing software. Further, compatibility with the large scale LIGMALS system used at the University of Michigan at ERIM is maintained so that additional processing modules in use at these locations can be rapidly incorporated for use when needed in developing countries.

Aside from the results obtained with the LIGMALS system, it has been shown that effective low cost processing programs can be designed and implemented in a developing country. This can be accomplished without requiring a major commitment to specialized hardware systems or the use of major software packages which require local scientists to go abroad to be trained in their use and modification. It has also been found that technical assistance at the beginning of such a development project will greatly speed the rate of progress in a developing country.

It is hoped that the results presented in this paper will encourage other individuals to attempt to expand their capabilities to include basic digital processing of remote sensing data.

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REMOTE SENSING AND GEOGRAPHICALLY BASED INFORMATION SYSTEMS*

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ABSTRACT

The incorporation of remotely sensed digital data in a computer-based information system is seen to be equivalent to the incorporation of any other spatially oriented layer of data. The growing interest in such systems indicates a need to develop a generalized geographically oriented data base management system that could be made commercially available for a wide range of applications. This paper reviews some concepts that distinguish geographic information systems and proposes a simple model which can serve as a conceptual framework for the design of a generalized geographic information system.

1. INTRODUCTION

Progress in the field of earth resources analysis, through the use of remotely sensed data, is resulting in the application of the developed analytical tools to meet the needs of a broad community of users. As an outgrowth, one sees the development of extensive geographically oriented data bases populated not only by scanner data, but also by a wide variety of associated data. A centralized data bank is envisioned as a tool to fulfill user information needs. The desire to make use of the information content of these data carries the responsibility to determine an effective means by which the data can be efficiently managed. It becomes imperative, then, to determine an environment, or information system, within which the data can be stored, retrieved, manipulated and displayed.

Information systems can be divided primarily into two categories: (1) object oriented, and (2) spatially or geographically oriented [1]. Object oriented systems include scientific or statistically oriented information systems and management information systems. In a sense, a spatial information system is nothing more than an object oriented system with an added attribute -- locational identifiers. It is just this characteristic, however, that adds to the complexity of storing, retrieving, and manipulating these data. For this reason one would wish to distinguish geographic information systems from object oriented systems.

Much effort has been expended in developing generalized data base management systems (DBMS) which are commercially available and well suited to the employment of object oriented data bases [2]. An advantage of commercially available DBMS is that a basic set of data management programs is made available that provides a starting point for a variety of applications. New users in the market for geographically oriented computer-based information systems (GIS) discover that a basic set of software designed for spatial systems is not commercially available.

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The user will respond by developing a local system that does not have general applicability, either by adapting a commercially available DBMS [3,4], or by developing independent in-house capabilities [5,6]. Each time such a system is developed effort is duplicated since the user has not been able to take advantage of the fact that there is a commonality to the data sets and data processing algorithms required in a basic computer-based geographic information system. It is precisely this commonality that makes the construction of a generalized spatial data base management system feasible.

The remainder of this paper simply proposes a way of thinking about a geographic information system that prefaces the construction of a generalized system. The paper is organized into four parts: (1) a general overview of geographic information systems that incorporate remotely sensed data, (2) idealized GIS standards, (3) the interrelationship of information system components, and (4) a GIS design model.

2. GENERAL OVERVIEW

Some general observations must precede the more technical discussion of the GIS design concepts. Spatially oriented data sets may be regarded as layers of information. The terminology stems from the common process of overlaying or intersecting layers of spatial data to extract information in regard to the co-occurrence of events. Remotely sensed and associated data can be viewed as different layers of spatial data, inherently grid, linear, or point source in structure. The incorporation of these data in a GIS data base is equivalent to the incorporation of any other spatially oriented layer of data. Assuming that each data layer has associated with it a unique storage structure, the display and analysis of these data require an interface between layers of both linear and grid structure, and of varying resolution sizes. Often it has been the restriction of data to a specific storage structure that has limited a system's scope of applicability. The development of a GIS that incorporates remotely sensed data will require special processing functions, which in turn will result in the need to manipulate non-spatial or object-oriented data. An example is the extraction of cluster signatures, i.e., sets of mean vectors and covariance matrices representing the statistical composition of a remotely sensed data layer. These statistics are not spatially oriented, yet once computed are integral elements of the data base.

The scenario, then, requires no restrictions limiting the data types (they may be spatial or not), data structures (they may be grid cells or not), or processing functions (the design must permit upwards compatible, modular growth so as not to limit the scope of applicability). What drives the system then? Simply answered -- the user. A generalized geographic information system must permit the user of the system multiple views of the data that are independent of the data storage structures. This basic axiom drives the concept of a generalized GIS.

3. ESTABLISHING SYSTEM STANDARDS

Designing a geographic information system first entails establishing system standards. The flexibility embodied in the basic axiom should also be thought of as first in importance among standards.

1. The user of the computer-based geographic information system must be permitted multiple views of the data independent of storage characteristics.

This simply means that although a data layer may be stored in polygonal format, the user may access it as if it were in grid cells. This imposes a responsibility upon the system to provide the appropriate interfaces. Other important standards include:

2. Applicability of the entire system as an organizational resource belonging to no one user or one application.
3. Applicability of the data to the users' needs.

4. Applicability of the data processing functions to the users' needs.
5. Efficiency of data storage, retrieval, and processing.
6. Provision of a 'user friendly' interactive and/or batch environment.
7. Fulfillment of cross-functional information requirements.
8. Fulfillment of cross-level information requirements.
9. Practicability within computer facility support.

Many of these standards are drawn directly from objectives which commercially available data base management systems aim to achieve [7]. It will become clear that the DBMS environment is required. The spatial nature of the data places special demands, however, on the data management system. The next step is to look at the various components of the information system in this context to establish distinguishing operational features.

4. GIS COMPONENTS

The task here will be to define "information system". The discussion will be in the context of a geographically oriented system. The scope of this subject is broader than the aspects of data base or of data management alone. The entire range of system components affects the manner by which spatial data are managed. For example, the processing of spatial data produces a need for requirements that place special demands on the data management system.

Figure 1 illustrates an interrelationship between the six components of an information system [8]. Two of these, "data specification" and "acquisition" pertain to the process of data creation. "Data management" and "data base" components pertain to the maintenance and retrieval of data in a computer-based environment. The information extraction processes are carried out at the "data processing" and "dissemination" stages. Each component will be discussed individually and, in some cases, interrelationships with other components will be discussed.

Data Specification

Data specification involves four basic processes [9]:

1. The establishment of specific data needs. These data needs may span a variety of data types including: land, environment, population, and administration. The selection of specific data types would be based on the system application.
2. The establishment of cross-level data needs, as well as cross-functional data needs.
3. Categorization of data types and interrelationships by topic and feature.
4. Determination of data update standards, based on the rate of data change and data growth through processing.

A unique characteristic of spatially oriented data is encountered once one initiates the process of data specifications. That characteristic is the "layered" nature of geographic data. That is, every location on the ground can have associated with it a wide variety of characteristics. One system employed at the Environmental Research Institute of Michigan defines 23 variables; like land use, soil and topography, to characterize a location of approximately one hectare in size. The same coordinate references many layers of information [10].

Data Acquisition

Probably the most awesome task confronting the implementation of any information system is the gathering of data in a computer-compatible format. This process takes on special problems when the data are geographically oriented. The tasks at hand include [9]:

1. Establishing data sources, i.e., determining which data are currently available and which data must be measured.
2. Establishing strategies for sampling.
3. Determining data computer compatibility. This may require a complicated digitization process to a standardized coordinate referencing system.

Here we are confronted with a second important spatial data characteristic. The volume of data required for even the small applications may be enormous. Spatially oriented data can exist in any one of three forms; point source data (climatological data), linear data (a street network), and areal data (thematic maps over contiguous regions). These data can be dimensioned not only by their spatial resolution, but also by their temporal resolution, i.e., rate of change as reflected in the frequency of measurement. As a familiar example, remote sensor data gathered by Landsat are segmented into frames. Each frame is 100 nautical miles on a side containing over 28,000,000 bytes of data. These data are measured every 18 days. Approximately 20 data sets are gathered over a given site in a year, representing over 0.5 billion bytes of data. Associated with these data, one may require a variety of other information: elevation from sea level at a point or land use category.

Data Base

By "data base" we mean the collection of pieces of quantitative and qualitative information, in a retrievable format, that measures or describes features of interest. The term "data base" is often misused, as is "data bank", for the information system itself. The information content of each piece of information or datum is three dimensional [8]: (1) thematic, what is being measured, (2) spatial, where it is being measured, and (3) temporal, when it is measured. Each datum can function either as an analytical variable (i.e., a measurement that can take on any numerical value over a continuous or interval scale) or a categorical variable (i.e., a descriptor or attribute that can take on a limited number of values on a discrete or nominal scale) or both. For example, multispectral scanner data are analytical, soil type data are categorical, and topographic information could be either or both.

The logical design of a spatially oriented data base includes the determination of the data layers or attributes, data interrelationships, and due to the potential volume of data, a data segmentation strategy.

Physical storage characteristics of geographically oriented data include two basic types: (1) regular cells or grid encoded data and (2) irregular cells or linearly encoded data, though each can be encoded in a variety of ways [11]. Traditionally, systems are of one type or the other. The fact that should not be compromised, however, is that certain layers of information fall naturally into one storage type or the other. The optimum system can manage both forms of data. Let us discuss the concept of the spatial data structure a little more fully.

Data structure refers to the manner in which data sets are arranged and the formats in which data elements are stored. The data structure enters at a variety of levels. Data can be found in each of the following structures:

1. Raw Data Structure: The form in which data are acquired, eg., soil map or MSS CCT format.
2. Computer-external Data Storage Structure: The computer-compatible format in which the data base resides outside of the computer processing unit.
3. The Computer-internal Data Storage Structure: The format in which the data reside within the computer processing system.

The external storage structure is the format from which data are initially retrieved before processing and by which data can be disseminated to various users. As mentioned, the two basic geographic information system external data structure organizations are line encoding and cell encoding.

In line encoding, spatial features are defined using nodes and connecting line segments. Point form data are described using only nodes; linear form data consist of nodes and connecting line segments; and areal data consist of nodes and line segments forming closed regions, i.e., polygons. Polygons need not be contiguous nor completely cover the scene of interest. The organization of the encoded nodes and line segments is generally handled through lists. Linear encoding techniques include: (1) location lists [12], (2) point-dictionaries [12], (3) DIME files [13], and (4) chain/node encoding [14]. Line encoding offers the most general type of geographic data representation [15] and is particularly advantageous in terms of computer storage requirements in describing: (1) large uniform regions of data such as state or county boundaries, i.e., regions that are large in area in comparison with the basic data cell size, (2) regions of irregular shape, and (3) features that are characteristically linear.

Cell encoding is a special form of line encoding of areal data. Cells are rectangular polygons and are usually square. Because of the regularity of the shapes, and since they generally cover an entire scene, cells can be stored as an array, rather than in a list. This form of encoding can permit an efficient way of retrieving certain kinds of data since access is done through coordinate referencing, i.e., indexing into the array, rather than searching through a list.

Grid structures include three encoding techniques:

1. Sequential. Data values are entered into cell after cell along rows or columns.
2. Compact Sequential. Repeating data values are not stored for each cell, but stored along with a length attribute.
3. Complete Coding. Each data value has a locational vector associated with it.

A third data storage structure type that is not always considered integral to the geographic data base are data that are not necessarily geographically oriented, but list oriented. Yet these data are so integrally related to the processing of geographic data that they should not be separated from it. Most systems manage these data in associated flat files. As previously mentioned, these data could include statistical characterizations of a particular layer of geographic data. Tables of aggregated statistical information that correspond to features of interest to the user of the system form another integral part of the geographic data base. These data types lend themselves to a DBMS data organization more readily than the geographically oriented data. However, due to their analytical nature, the data values fall in a continuum and are thereby not easily retrieved using inverted lists, which function best in an environment of discrete data values. A relational environment is more appropriate [16].

Data Management

We have seen, so far, that geographic systems are characterized by: (1) the spatial orientation of the data, (2) the layered characteristics of the data, (3) the potential volume of data, and (4) the variety of optimal data structures. These characteristics create a few problems for the subsystem responsible for the management of these data. Let us speak of data management in the CODASYL sense [17]. That is to say, the data base management subsystem is aware of a logical data structuring, and is responsible for the retrieval of these data in a manner that assures data integrity and application programs that can remain independent of data storage.

The retrieval demands of a GIS preclude the direct employment of a commercially available DBMS. Retrieval functions include retrieval based on nominal data characteristics, coordinat data designation and relational techniques. Furthermore, the analytical and continuous nature of certain data causes the inverted list approach to the retrieval of the data to become inefficient. The commercially available DBMS encounters other obstacles. Whereas spatial data may be stored as a polygon, a structure that is not supported by commercial DBMS's, the user may require the data in grid format requiring the DBMS to

invoke a data base procedure called, say, point-in-polygon, which will convert the irregularly shaped data into a grid cell matrix (responsive to the basic design axiom), again not supported by available DBMS's. Furthermore, the user's point of view may require a data resolution different from that available, resulting in a complicated resampling of these data. The result of these inadequacies of commercially available systems in the development of various spatial information systems has been the local implementation of data management systems. Often features that make the CODASYL systems of value were lost, especially program/data base physical storage independence. It should be re-emphasized that, though commercially available systems fail to meet the data management needs of a geographic system, the characteristics of such systems can be designed into a spatial data management system.

Data Processing

The processing of spatial data quite often is analytical in nature and generates new layers of spatial information that must be maintained by the data base management subsystem. Data base growth, therefore, comes not only from the specification and encoding of raw data types, but also from the processing of encoded data. Whereas a data management system attempts to preserve data base and application program independence, the nature of the application programs employed may affect the data supported in the data base.

Processing of spatial data falls logically into three steps: preprocessing, processing, and post processing.

The intent of data preprocessing is not to extract information from the encoded data, but to modify the data in such a manner as to make the extraction of information more feasible or efficient.

Data preprocessing generally deals with such items as transforming raw data into some standard coordinate referencing system like Universal Transverse Mercator. This activity is termed geometric correction. A second preprocessing activity might involve the analytical transformation of data. For example, many forms of spatial data, in particular those measured using remote sensors, are multivariate in nature. A principal component analysis of the data may warrant a transformation to compress the data into fewer dimensions with axes oriented in the direction of the principal components. In effect, a new layer of data is produced.

Data processing of the spatial data pertains to the information extraction process. This involves three basic operations:

1. Feature extraction in response to a user's query within a layer of data, eg., a discriminant analysis to determine physical characteristics of the data.
2. Feature extraction between layers of data; commonly this is accomplished through co-occurrence analysis or overlay processing; here layers of data are "intersected" to determine geographic regions that satisfy a user specified query that may be algebraic in nature.
3. Inference modeling; the information content of the data is used in conjunction with a mathematical model to project changes that may occur, eg., an ecological system over a period of time under a set of circumstances.

Data post-processing pertains to the aggregation of information extracted in the data processing stage. Statistics are gathered into a format compatible to some report or tabular display. Oftentimes the sequence of data processing efforts is an interactive one. The post-processing of the data may warrant another processing approach to extract new or different forms of information.

Dissemination

Dissemination pertains to the delivery and maintenance of data and information extracted from data to the users of the system. At a local level, data

are disseminated to the users through some sort of hard or softcopy interface in the form of a map or a report. That report may be generated as a response to a query language interface with the system user. It may take the form of a table, chart or graph. The standard vehicles designed to transport these data would include a line printer, a table plotter, or a video terminal with associated hardcopy unit.

Dissemination of spatial data and information both begins and ends the cycle of a geographic information system. The information extracted may be the computation of a new layer of data which is in turn re-entered into the system for further processing and analysis, or may be a final report describing the results of data processing and analysis.

5. COMPUTER-BASED INFORMATION SYSTEM MODEL

The preceding discussion addressed the concept of a spatial information system. The intent was to indicate the special features of such a system that make the management of the data components unique through definition of the variety of system components. An attempt was made to indicate the special data management requirements that do not fit into the scope of commercially available data base management systems. The contention was made, however, that a spatially oriented data base can be managed through a general system that is designed especially for spatial data, and at the same time remain within the philosophical structure of a DBMS as defined by the CODASYL Data Base Task Group [18]. The following proposed model attempts to adhere to this philosophy.

The basic principle followed in the proposed model pertains to the interface between user and data. The user will be allowed multiple views of the data, independent of the physical storage of the data. For example, if Landsat data 'A' and aircraft data 'B' are to be processed, the user may specify:

GET A, B GRID RESOLUTION = hectare

indicating that each data set is retrieved in a grid format at a hectare size resolution. Alternatively, the data labeled 'B' could have been polygonal data. The same request would have necessitated the employment of a polygon to grid algorithm. The user sees grid data of similar resolution, even though the storage of these data are not necessarily grid in structure nor similar in resolution. Structurally, (see Figure 2) the system is a Data Base Management System with the addition of a user/system interface through a batch or Interactive Processing Language (IPL). Each element will be examined more closely.

Data Storage Management

Geographic data are distinguished, as mentioned previously, by the methods employed to retrieve the data. This in turn is reflected in the data's physical storage structure. The data base manager is responsible for those storage structures. It is informed of the particular structures and data sets active in the data base through the data definition created by a data base administrator through the data definition language (DDL).

Data Base Manager (DBM)

The data base manager is a set of software programs that interfaces between a user or program request for data and the physical representation of those data in storage. This software needs to be aware not only of the data sets that comprise the data base but also of the permissible methods of retrieval. For example, a user may not request signatures to be retrieved in polygonal format, though he may retrieve polygonal data in grid format. The DBM passes the user request for data and invokes format service routines (FSR's) available to establish a working data set which will be processed by the application programs. The DBM learns the data structure through the data definition language (DDL) and communicates with the processing system through the data manipulation language (DML).

The Data Definition Language (DDL)

Before a data base is created, the administrator of the data is responsible for determining what data types will be employed. Joined with this responsibility is the need to establish the physical storage characteristics permitted for each data type, the permissible retrieval mechanisms, and whatever logical linkages may occur between data types. The definition of a data type must here be distinguished from the occurrence of a data type. The administrator does not load the data base, at this point, with real data, but defines the types of data that are permitted in the data base. These data definitions are then communicated to the data base manager using a data definition language. A data definition would include as a minimum: (1) the data type name, (2) the physical storage specification, (3) permitted linkages between other data types, and (4) permitted retrieval formats. The data base manager would invoke a data definition generator which would construct internal tables designating the permissible data types and structures.

Data Manipulation Language (DML)

Interaction between application programs and the data base is through a data manipulation language that is interpreted by the data base manager. Typically, a DML would consist of five or six verbs hosted in another language through subroutine calls. DML verbs could include the following (or their equivalents):

```
STORE  -- which would create the occurrence of a data type,
        i.e., load the data base

GET     -- to retrieve data

FIND    -- to locate data

MODIFY  -- to alter data

DELETE  -- to remove data
```

Each verb would in turn be modified appropriately to supply the data base manager with sufficient information for successful data interface. For example, a prototype GET command may consist of:

```
GET dataset(s) mode in-location modifiers
```

where one or more data sets would be retrieved in grid, polygonal, or list mode and stored at "in-location" as modified by "modifiers" (eg., resolution, region).

Data Processor

Five basic needs arise: (1) a grid data processor, (2) a linear data processor, (3) a signature processor, (4) list data processors, and (5) data display mechanisms, eg., graphics. This paper does not address engineering of these needs. The significant point to be stressed is that the data set processed will be that set termed the "active data set" and prepared to satisfy the current user's view of the data in the data base.

The User

The processing system and user interface through batch-mode operation or interactively through an interactive processing language (IPL). This is to say that the typical user is not a programmer, hence the user is supplied with a very high-level language interface. The supplied vocabulary depends, of course, on the processing functions available in the system.

6. CONCLUSION

A geographic information system is viewed as an organizational resource that serves more than one user. However, not every user's view of the data is the same. In order to support multiple views of the same data, the data base manager is provided as the data/program/user interface. The same skeleton system and supportive software can be supplied to any user employing geographically oriented data. Specific modules can then be developed to resolve the needs of the particular application. Those modules, being data storage independent, need not concern themselves with data base formats. This design provides the following advantages:

- Permits multiple views of the data
- Separates data from data processing functions
- Provides integrated collection of data
- Provides centralized and efficient control of data
- Provides independent management of data security, quality, and integrity
- Minimizes duplication of data
- Automates data filing efforts
- Provides high-level interface for a wide variety of users

Most importantly, a generalized approach to the definition and design of a geographic information system can provide a tool adaptable to different users and different applications.

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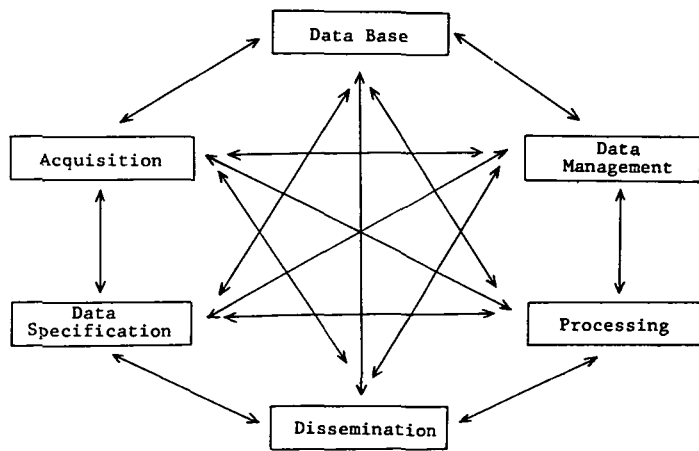


FIGURE 1 SCHEMATIC REPRESENTATION OF THE RELATIONSHIPS BETWEEN COMPONENTS OF AN INFORMATION SYSTEM

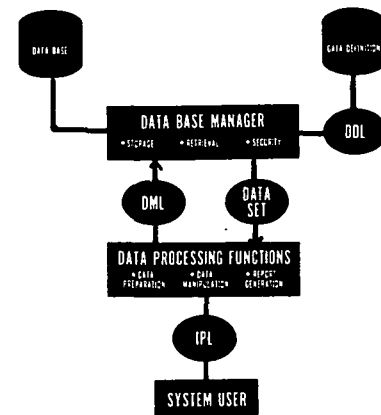


FIGURE 2. A GIS DESIGN MODEL

INTEGRATION OF REMOTE SENSING AND
SURFACE GEOPHYSICS IN THE DETECTION OF FAULTS

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ABSTRACT

Possible faults indicated by remote sensing can be quickly confirmed by resistivity surveys. Anomalous resistivity values occur within the fault crush zone. In a sedimentary region in Rio Blanca County, north-west Colorado, a fault zone was inferred from LANDSAT imagery. Subsequent resistivity surveys indicated substantial resistivity highs associated with the faults. Seismic data and the drilling of an observation well confirmed the main fault.

1. INTRODUCTION

Remote sensing was included in a comprehensive investigation of the use of geophysical techniques to aid in underground mine placement. The primary objective was to detect faults and slumping, features which, due to structural weakness and excess water, cause construction difficulties and safety hazards in mine construction.

Preliminary geologic reconnaissance was performed on a potential site for an underground oil shale mine in the Piceance Creek Basin of Colorado. LANDSAT data, black and white aerial photography and 3-cm radar imagery were obtained. LANDSAT data were primarily used in optical imagery and digital tape forms, both of which were analyzed and enhanced by computer techniques. The aerial photography and radar data offered supplemental information.

Surface linears in the test area were located and mapped principally from LANDSAT data. A specific, relatively wide, linear pointed directly toward the test site, but did not extend into it. Density slicing, ratioing, and edge enhancement of the LANDSAT data all indicated the existence of this linear. Radar imagery marginally confirmed the linear, while aerial photography did not confirm it.

A resistivity mapping survey through the test site and perpendicular to the remotely sensed linear indicated a substantial resistivity anomaly (high) across an extension of the linear. A parallel resistivity survey line confirmed that the anomaly was aligned with the linear. Resistivity differences between fault zones and their environs are due to the comparatively high moisture content within the zone to produce a resistivity low, and, either calcification or drainage of moisture (leaving comparatively large interstices) to produce a resistivity high.

The existence of the faults were further confirmed by a refraction seismic survey, and by drilling an observation well in which rubble was found, indicating a fault crush zone.

2. GEOLOGIC SETTING OF TEST SITE

The area of concentration for this study is located in Fault Draw, a sub-tributary valley of Ryan Gulch at approximately 39°55' north latitude and 108°20' west longitude (section 6, R 97W, T 2S). Ryan Gulch is situated in the north-central part of the Piceance Creek Basin, Rio Blanco County, Colorado. Fault Draw is important, for here the U. S. Bureau of Mines initiated a test drilling to determine the feasibility of an underground oil shale mining operation. Figure 1 is a topographic map of the test site area.

Structurally, the test site lies about 15 kilometers from the center of a domal uplift where commercial gas fields are found. The arcuate shape of Piceance Creek indicates that it is a consequent stream to this domal uplift. A graben and its associated topographical expression (Dudley Bluffs) extends at least 25 km from Collins Gulch in the domal uplift to Yellow Creek, which is about 9 km west-northwest of the test site. As this extensive structural feature passes closely by or encompasses the test site, which is also close to the large domal uplift, other structural features such as tension faulting would be plausible in this region.

Bedrock exposed at the Fault Draw/Ryan Gulch area is yellow-brown sandstone of the Uinta Formation. It can be seen along the valley walls and especially at the junction of the two valleys. Near the mouth of Fault Draw along the north-western wall of Ryan Gulch are the best exposures, where visible evidence of the Dudley graben can be found. Running across Ryan Gulch and bordering near the mouth of Fault Draw are two normal faults which form the graben. Within the sandstone outcrop northeast of the mouth of Fault Draw can be seen a white segment of calcite, presumably filling the southern member of the pair of faults. The vertical displacement of the graben is approximately 50 feet.

Extensive jointing, characteristic of the Uinta Formation throughout the basin, results in poor resistance to weathering, and makes the formation one of the principal aquifers of the area. Random outcrops of bedrock core appear through the unconsolidated materials which blanket and shape the rolling hills.

3. REMOTE SENSING DATA

Three types of remote sensing data were used in the study: black and white aerial photography, X-band synthetic aperture radar (SAR) imagery, and four-channel MSS LANDSAT data. These three types of imagery are available to the public at nominal cost and with little delay. Particularly with the more sophisticated LANDSAT and SAR data, an array of interpretive techniques can be used. These techniques range from simply viewing and interpreting a single image to that of complexly performing computer analysis using statistical and other comparisons of several images. In this study several computer analysis techniques were used on the imagery.

The LANDSAT data was the primary source of finding unmapped linears. Aerial photography and imaging radar data provided supplemental information. The four channels of LANDSAT data are shown in Figure 2.

An alternative format of LANDSAT data is computer compatible tape, which can be exploited on the computer. Computer analysis involved level slicing single and two-channel ratio images to attempt to determine whether any structural or lithological information could be obtained about fault systems in the area. The image, a "graymap", is composed of selected symbols on a computer printout. The computer analysis was performed on the University of Michigan

AMDAHL computer using a Department of Natural Resources LIGMALS program. The black and white stereo aerial photography with a scale of 1:60,000 is shown in Figure 3. Piceance Creek and Ryan Gulch form the partially cut off "A" in the lower right-hand corner of the image. The cross of the "A" is a portion of a long linear composed of Dudley Bluffs and associated graben which is oriented approximately N25E. Aerial photography provided supplemental data in the form of topographic, vegetation and stream pattern information.

Side looking radar imagery was also utilized in the study. The synthetic aperture radar (SAR) imagery was obtained with a wavelength of 3 cm (X-band) radar (Brown and Porcello, 1969). The imagery was provided courtesy of the Strategic Air Command, and is available from Goodyear Aerospace Corporation, Litchfield, Arizona.

4. INTERPRETATION OF REMOTE SENSING

Several linear features are interpreted as faults which geologic maps of the area confirm. There are some structures noted on the imagery as suspected faults which have not been mapped on the geologic maps. Trexler (1974) mapped anticlinal and synclinal folds and faults throughout the Piceance Basin using photographic interpretive techniques on single channel LANDSAT images.

Stereo photographs (Fig. 3) confirm some but not all of the geologic structures discerned on LANDSAT. Near the test site, Dudley Bluffs with its associated fault zone are clearly visible on both LANDSAT and aerial photography. However, the aerial photography only indicates a single fault feature - Dudley graben. A more dense band of vegetation at the known location of the graben appears to be a result of the zone of brecciation and consequent moisture within the graben.

Figure 4 is a 5/7 ratio processed graymap produced by point-by-point ratioing of LANDSAT Band 5 by Band 7. The "A" (without the cross) in the upper portion of the figure is the intersection of Ryan Gulch and Piceance Creek. The ratioing process performed in this image tends to suppress variation in illumination due to topography and viewing angle. For example, Dudley Bluffs and graben (the cross of the "A") is suppressed in this figure. Thus, differences in this image can be attributed to variations in the composition (i.e., lithography, mineralogy, moisture, vegetation) rather than the topography. The 5/7 image clearly delineates the alluvial deposits (chiefly silt, sand, and gravel) from the surrounding green river bedrock (gray and yellow-brown marlstone, siltstone, sandstone and tuff).

In the middle of the upper portion of Figure 4, above the Ryan Gulch - Piceance Creek intersection, a bright linear about 1/8 inch in width can be seen. The extension of this linear extends directly through the test site. This is the linear which aligned with the resistivity anomaly, and an observation well at Fault Draw which indicated faulting. This extension into Fault Draw is termed Burdick's Fault. Aligned with this linear, but not extending as far south as shown on LANDSAT imagery, are a series of three faults shown by Welder (1971).

It is this linear which demonstrates the utility of commencing reconnaissance with the easily available, inexpensive remote sensing data. This linear is not associated with topography, and therefore had been previously overlooked as a possible fault zone.

Figure 5 is a channel 5 density sliced image that is intended to show a series of linears in close proximity to the test site. Linear A appears to be the same linear enhanced on the 5/7 ratio image previously shown.

The final sets of results are edge enhanced images of LANDSAT band 5 and the 3 cm SAR data. The image enhancer is a spatial data color enhancer loaned

to ERIM by Spatial Data Corporation of Goleta, California. An edge enhancement mode that accents subtle density differences was used for this study. Through edge enhancement a series of linears were displayed that run northeast-southwest through Piceance Dome into the test site. These linears were not indicated on geologic maps of the area. Linears in other directions were also displayed.

Figure 6 shows the normal Band 5 LANDSAT image, along with the resulting edge enhanced image of the test site. The linear aligned with the resistivity anomaly through the test site is evident on both images.

In Figure 6, note the clear indication of a linear aligned with Ryan Gulch extending northeast toward the White River uplift. Although outside our test area, this long, persistent linear concerns the test area. If this linear were subsequently proven to be a fault through further geologic or geophysical investigation, it would indicate more structural activity than previously thought to be the case within the test region. Also, the straight portion of Ryan Gulch might be fault controlled. This northeast linear is also present on the four LANDSAT channels shown in Figure 2. Figure 7 is a SAR image of the test site area which does not indicate this linear.

5. GEOPHYSICAL CONFIRMATION

Because a fault crush zone consists of broken particulate matter, it usually possesses a different resistivity than the surrounding country rock. Resistivity highs are produced by crystallization or calcification due to fluid transport within the fault, or by relatively large particles which do not retain water. Resistivity lows are produced by the retention of water by relatively small particles within the fault zone.

Mapping resistivity surveys across a suspected fault can be used to confirm the existence of a fault. An economical and timely method of resistivity mapping is that of taking successive measurements along a baseline using a Wenner array (Parasnis, 1966). This simple configuration consists of four in-line electrodes equally spaced. The two current electrodes are at the ends of the line, the two voltage electrodes near the center. Under conditions of constant current input through the current electrodes, the voltage difference between the voltage electrodes indicates the apparent resistance of the earth under the electrodes. The effective depth of measurement is proportional to the spacing of the electrodes. If the array of electrodes is moved with successive measurements along a line crossing a resistivity anomaly, a plot will indicate the location of the anomaly.

At our test site resistivity was mapped across the area which the extension of the remotely sensed linear indicated. Fifty foot electrode spacing was used. A substantial resistivity high was found. Resistivity was then mapped 400 meters away on a line parallel to the first line, and another substantial resistivity high was again found. The two resistivity highs aligned with the remote sensed linear.

Figure 8 is a photograph of the test site showing the placement of the resistivity survey lines. The dashed line represents the location of the inferred fault. Figure 9 shows the resistivity profiles of the two lines. The first had an anomalous, apparent resistivity high of 750 ohm meters, the second of 1600 ohm meters. The average resistivity in this region is approximately 100 ohm meters. In Figure 9 the two lines showing the substantial resistivity high were on elevations away from the alluvium of the draw. Two more lines, between the outer two, are on alluvium, and show modes rises when crossing the fault.

The fault was fully confirmed by drilling, and later by a seismic survey with 20-foot spaced geophone arrays.

6. DISCUSSION

One of the major geological uses of remote sensing has been the mapping of previously unknown linears. Both LANDSAT and synthetic aperture radar imagery have proven very useful in such mapping. In many cases these linears turn out to be faults.

These faults can be confirmed by surface geophysical measurements, one of the most economical and timely being resistivity. Several advantages of resistivity surveys are:

1. Instrumentation is simple and comparatively inexpensive.
2. Minimal skill is required of a small crew.
3. Data can be gathered under any noise condition, such as heavy machinery.
4. Immediate reduction of the data enables one to search out the geometry of the anomaly during the data gathering phase.
5. The data, although not uniquely interpretable, are in a straightforward form that is easily and clearly understood by the non-geophysicist.

Although the experiment conducted here was for mine placement, the confirmation of faults by resistivity can aid in solving other problems. For example, in searching for underground water sources in arid and semi-arid regions. In these regions sources of water are often fault controlled. A relatively inexpensive resistivity mapping survey would greatly improve the confidence that water might be found before commencement of expensive drilling.

Depending upon the cost of the operation to be performed--whether mine placement, water drilling, mineral exploration, etc.--other surface measurement techniques such as seismics can be used for further confirmation of the existence of faults.

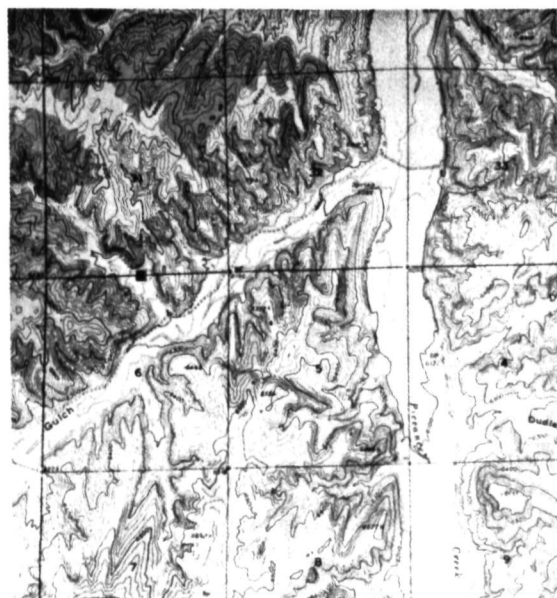


FIGURE 1. TOPOGRAPHIC MAP OF TEST SITE REGION. Black square on central horizontal section line is the location of the observation well. (USGS Square S Ranch Quadrangle, Colorado)

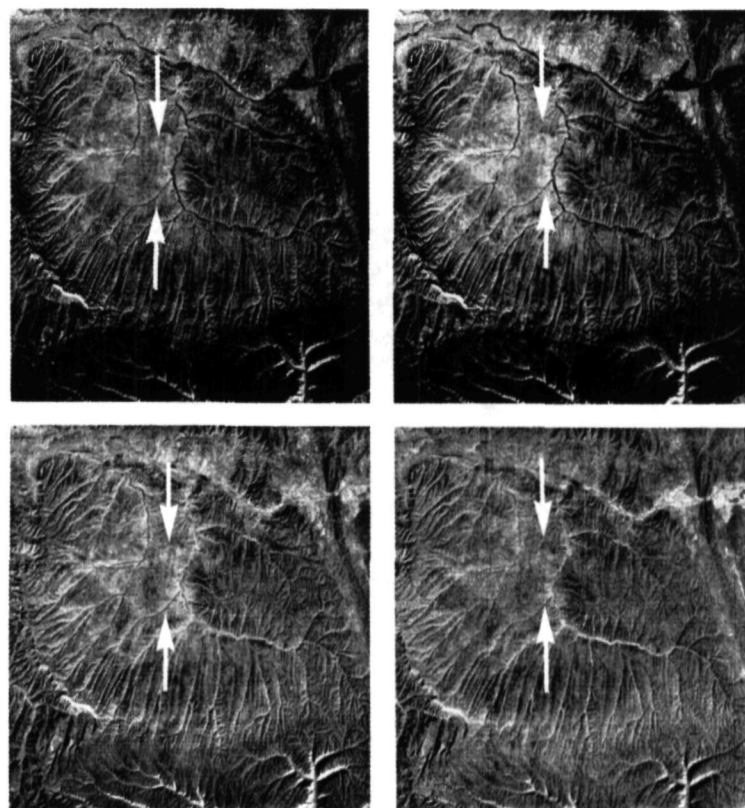


FIGURE 2. FOUR CHANNELS OF LANDSAT IMAGERY. $\begin{pmatrix} 4,5 \\ 6,7 \end{pmatrix}$ Primary linear indicating fault is between arrow heads.

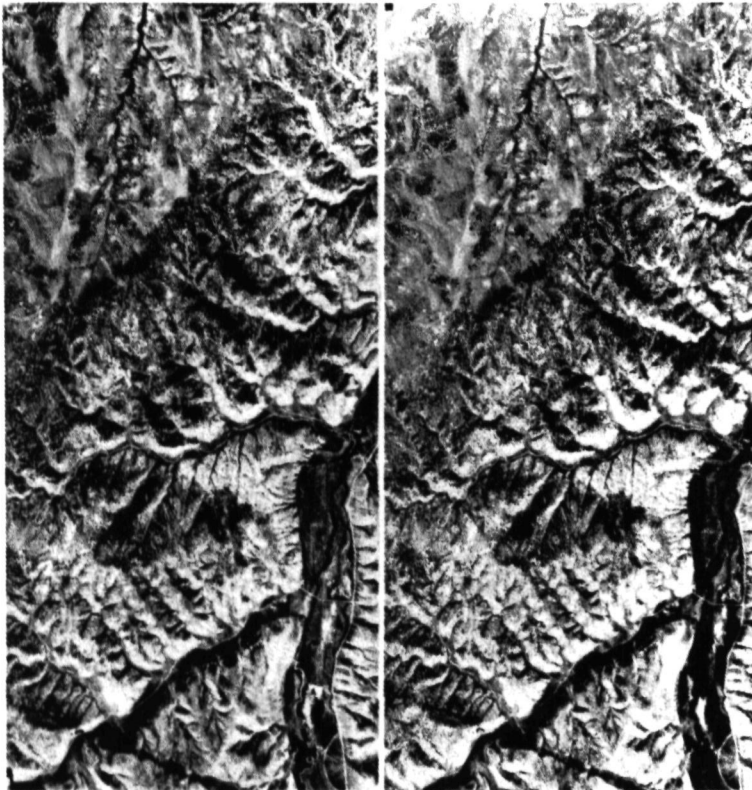


FIGURE 3. STEREO PHOTOGRAPH OF TEST SITE REGION.

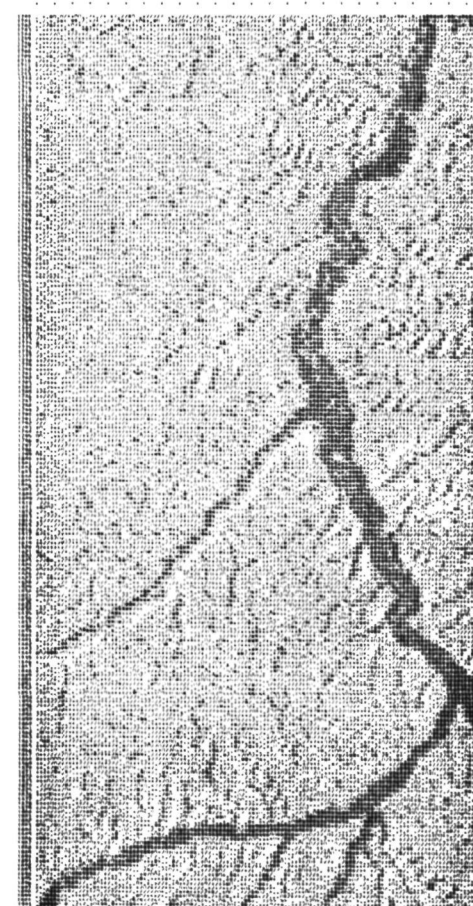


FIGURE 4. RATIO PROCESSED GRAY-MAP PRODUCED BY POINT-BY-POINT RATIOING OF LANDSAT BAND 5 BY BAND 7. Note light, relatively wide vertical linear at top center.

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FIGURE 5. DENSITY SLICED IMAGE OF LANDSAT BAND 5. Light areas occur along wide vertical linear.

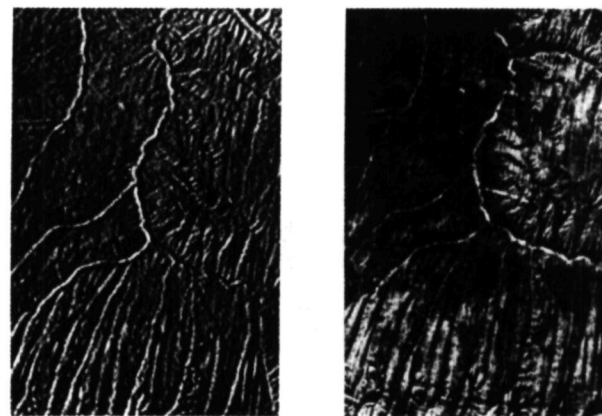


FIGURE 6. LANDSAT BAND 5 IMAGE (LEFT) AND EDGE ENHANCED IMAGE OF TEST SITE (RIGHT).



FIGURE 7. SAR IMAGE OF TEST SITE REGION.

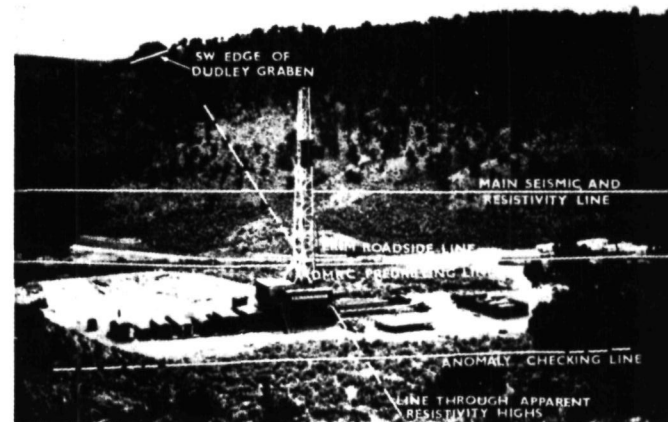


FIGURE 8. PHOTOGRAPH OF TEST SITE SHOWING OBSERVATION WELL, RESISTIVITY AND SEISMIC LINES, AND DASHED LINE THROUGH RESISTIVITY HIGHS WHICH INDICATES THE FAULT.

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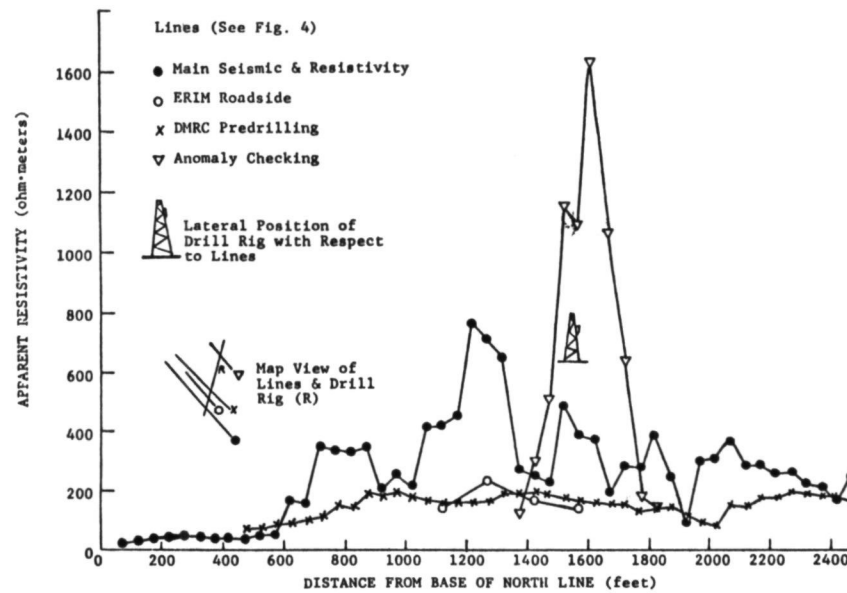


FIGURE 9. APPARENT RESISTIVITY PROFILES
ON FOUR LINES IN TEST SITE. (See Fig. 8)

EVALUATION OF ALGORITHMS FOR GEOLOGICAL THERMAL-INERTIA MAPPING

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ABSTRACT

The errors incurred in producing a thermal-inertia map are of three general types: measurement, analysis, and model simplification. To emphasize the geophysical relevance of these errors, we express them in terms of uncertainty in thermal inertia and compare these uncertainties with the thermal-inertia values of geologic materials. Thus the applications and practical limitations of the technique are illustrated.

All errors are calculated using the parameter values appropriate to a site at the Raft River, Id. Although these error values serve to illustrate the magnitudes that can be expected from the three general types of errors, extrapolation to other sites should be done using parameter values particular to the area.

Measurement errors introduced by multispectral scanning systems commonly range from a noise-equivalent-temperature difference (NEAT) of 0.1K for aircraft systems to 1K for satellite systems. The resulting uncertainties in thermal inertia range from 15 TIU (thermal-inertia unit)* to 150 TIU.

Three surface temperature algorithms were evaluated: linear Fourier series, finite difference, and Laplace transform. In terms of resulting errors in thermal inertia, the Laplace-transform method is the most accurate (260 TIU), the forward finite-difference method is intermediate (300 TIU), and the linear Fourier series method the least accurate (460 TIU). However, the two more exact methods require more computer time, and both lack the ability of the Fourier-series algorithm to illustrate the physical significance of individual terms. By comparing the errors with the range of thermal inertias of geologic materials, it is possible to select the most cost/effective algorithm for a particular application.

Model simplification errors result from three sources: transient effects, topography, and surface coating effects. For example, flux of 35 watts/m² (equivalent to a water evaporation rate of 1.2 mm/day) would produce a thermal-inertia error of about 200 TIU. If no topographic corrections are made, a 10° southwestern slope causes an error in thermal inertia of about 350 TIU. A hematite surface coating one centimeter thick on a rock will produce an error of approximately 200 TIU, whereas a one-millimeter layer thickness will have a negligible effect (25 TIU).

The total system errors in thermal inertia are placed in geologic context by noting the separation in thermal-inertia values for various geologic materials. For example, the thermal-inertia separation between limestones and dolomites is typically 1200 TIU. The error analysis technique indicates that thermal-inertia discrimination should be possible between black shale and gabbro (separation of approximately 450 TIU); discrimination between these two materials was not possible using Landsat spectral-reflectance data.

Errors in thermal inertia can be translated into errors in bulk density and moisture content. Thermal-inertia mapping from aircraft (NEAT = 0.1K) has an accuracy of about 1% in bulk density or equivalently, a sensitivity of 0.3% in water content. From satellite (NEAT = 1K) these accuracies are 9% and 3% respectively.

A practical evaluation of the error analysis is demonstrated for aircraft data acquired at Raft River, Id. We cannot discriminate the tuff from the alluvium, having a lower thermal inertia, and the lava, having a higher thermal

* TIU = 1 watt · sec^{1/2}/m²/K

inertia, without a topographic correction, but we can discriminate the lava flows from the alluvium.

1. INTRODUCTION

Thermal-inertia mapping is a recently developed technique that allows discrimination among geologic materials [1], [2], [3], [4], [5], [6]. The purpose of this paper is to discuss the types and magnitudes of errors encountered in applying this technique and to express these errors in a geologically meaningful way. The errors are of three major types: measurement errors, analysis errors, and model simplification and assumption errors. The major focus of this paper is to develop a procedure to select an algorithm which is appropriate to the geologic application and which minimizes computer time.

In addition to presenting the mathematical basis for the three algorithms, we provide a numerical evaluation with respect to an exact solution. Estimates of the errors due to measurement and model simplification are combined with the analysis errors, and all errors are expressed as uncertainties in thermal inertia. These combined errors are compared to the thermal-inertia values determined for some selected geologic situations. As an illustration of the analysis technique, the Fourier-series algorithm is applied to the construction of a thermal-inertia map of an area in the Raft River, Id.

2. MATHEMATICAL BASIS

Thermal inertia is a physical property of geologic materials, and its value can be determined by measurements of the diurnal variation of surface temperature and the albedo of the surface. A physical model for the surface temperature variation is therefore required.

We assume one-dimensional, periodic heating of a uniform half space of constant thermal properties. The ground temperature obeys the diffusion equation:

$$\kappa \frac{\partial^2 v(x,t)}{\partial x^2} = \frac{\partial v(x,t)}{\partial t} \quad (1)$$

where $v(x,t)$ is the ground temperature at a distance x below the surface and a time t , and κ is the thermal diffusivity.

To solve this equation for the surface temperature, we require a form of the solution appropriate to the diffusion equation and the boundary condition, which assumes conservation of energy over the diurnal cycle. Before looking at possible forms of the solution, we need to investigate the boundary condition.

If we assume a heat-balance condition exists at the surface, then the incoming heat fluxes--the incident solar radiation (I), the sky radiation (S), and the geothermal heat flux (Q)--must balance the outgoing fluxes--the convective flux (C), the evaporative flux (E), and the ground reradiation flux (R). The resulting expression of the heat flux at the surface is:

$$-K \left. \frac{\partial v(x,t)}{\partial x} \right|_{x=0} = I + S + Q - C - E - R \quad (2)$$

where K is the conductivity of the material. The convective and evaporative fluxes are included in equation 2 for completeness; however those terms will be handled only qualitatively in this paper.

The parameter of interest, the surface temperature, is present in equation 2 in the heat-conduction term (the left hand side of equation 2) and in the ground-reradiation term (R). Equation 2 is rewritten to display the surface temperature:

$$-K \left. \frac{\partial v(x,t)}{\partial x} \right|_{x=0} = -\epsilon \sigma v(0,t)^4 + a(t) + Q \quad (3)$$

where ϵ is the mean emissivity of the ground, σ is the Stefan-Boltzmann constant, $a(t)$ is a term combining the time-dependent solar flux and sky radiation flux and thus includes the surface albedo and emissivity, and Q is the geothermal heat flux. This expression must be satisfied for any equational form of $v(x,t)$ chosen for the solution to the diffusion equation. The nonlinear form of this boundary condition prevents a direct analytical solution of the diffusion equation. An exact numerical solution can be calculated [7]; however, the complexity, the difficulty of illustrating the physical significance of terms, and the computer costs all provide incentive for investigating less exact algorithms.

One method of handling the nonlinear boundary condition is to linearize it and to express the solution to this condition in an exact form as an infinite Fourier series. The linearization is achieved by performing a Taylor-series expansion of the surface temperature around the sky temperature and discarding quadratic and higher order terms. This solution has been discussed in detail by Watson [1], and the form of this solution is:

$$v(0,t) = T_{\text{sky}} + \frac{Q}{S} + (1-A) S_0 C \cdot \sum_{n=0}^{\infty} \frac{\cos(n\omega t - \epsilon_n - \delta_n)}{\sqrt{(s+r\sqrt{n})^2 + (r\sqrt{n})^2}} \quad (4)$$

where

$$s = 4\epsilon\sigma T_{\text{sky}}^3$$

$$r = P\sqrt{\frac{\pi}{\tau}}$$

$$\tau = \frac{2\pi}{\omega}$$

$$\delta_n = \tan^{-1}\left(\frac{r\sqrt{n}}{s + r\sqrt{n}}\right)$$

and T_{sky} is the sky temperature, A is the ground albedo, C is an effective atmospheric-transmission factor, S_0 is the solar constant, Q is the geothermal heat flux, A_n and ϵ_n are the amplitude and phase of the n th harmonic of the insolation, and P is the thermal inertia.

Another method of solving the diffusion equation is to use the exact, nonlinear boundary condition and to apply a finite-difference iterative technique [9]. This solution assumes the form:

$$V_{m+1,n} - 2V_{m,n} + V_{m-1,n} = \frac{(\Delta x)^2}{\Delta t \cdot \kappa} (V_{m,n+1} - V_{m,n}) \quad (5)$$

where $V_{m,n}$ is the ground temperature at a time, $n\Delta t$, and distance from the surface, $m\Delta x$; Δx and Δt are small increments in distance and time; and κ is the diffusivity.

The forward finite-difference method requires an initial solution and propagates this solution forward in time. To insure continuity at the boundary, the heat-balance boundary condition must be satisfied. The boundary condition for the forward finite-difference solution is expressed as:

$$V_{0,n+1} = V_{1,n+1} + \frac{\Delta x}{K} f\{V_{0,n+1}, (n+1)\Delta t\} \quad (6)$$

where K is the conductivity and f is the flux (eq. 2).

Numerical stability and convergence put constraints on the size of the time and distance increments. To insure these errors do not grow, the stability condition

$$\kappa \cdot \frac{\Delta x}{(\Delta t)^2} \leq 0.5 \quad (7)$$

must be met [9].

The third method of solving the diffusion equation is to use the nonlinear boundary condition and to apply Jaeger's method of Laplace transforms [7]. This method has the advantage that it directly yields the surface temperature without requiring an estimate of the temperatures at depths. However, the solution also must be iterated due to its nonlinear form:

$$F_n = \frac{P}{\sqrt{\pi\tau}} \cdot \sum_{s=1}^m v_s \phi_{n-s+1} \quad n=1,2,\dots,m \quad (8)$$

where F_n is the average flux into the ground in the n th time interval; P is the thermal inertia; τ is the period of the heating flux; v_s is the average surface temperature in the s th time interval; and the ϕ 's are a set of numerical coefficients determined solely by m , the total number of intervals in τ . A detailed description of this method can be found in Jaeger [7] for the periodic heating of a half space, and the method was extended by Watson [8] to the heating of a layer over a half space.

3. ANALYSIS ERRORS

The previous section presents the mathematical basis for the three algorithms used to compute the diurnal surface temperatures (eq. 4, 5, 8). In this section, we numerically compare the errors by expressing the temperature differences as equivalent differences in thermal inertia. The difficulty in perceiving the physical significance of terms and the amount of computer time required for each algorithm are also discussed.

The evaluation of the algorithms in terms of uncertainties in thermal inertia is performed in two steps. The first is to compare the three algorithms with each other by approximating the incident solar flux as a sinusoidal half wave. The second step is to compare the most exact algorithm--the Laplace transform--with an exact theoretical solution--a pure sinusoid flux. This establishes the relationships of the three methods to the exact solution. The resulting errors in thermal inertia for each of the algorithms compared to the exact solution are:

Laplace-transform Algorithm	260 TIU
Finite-difference Algorithm	300 TIU
Fourier-series Algorithm	460 TIU

Table 1 gives the list of parameter values used to make the above comparison.

The relative ordering of the algorithms with respect to accuracy is as expected: the Laplace-transform algorithm, which is an implicit relationship between surface temperature and surface flux, is the most accurate; next the finite-difference solution; and lastly the Fourier-series algorithm, which linearizes the radiation-transfer terms. The magnitude of the errors can be made more geologically meaningful by noting that soils typically have thermal inertias in the range of 500 to 2000 TIU and that rocks typically have a range of thermal inertias of 2000 to 4000 TIU. (A more detailed discussion of the thermal inertias of geologic materials is presented in the discrimination of geologic materials section.)

An important consideration in the cost/effectiveness of thermal-inertia mapping is the computer time required to solve the various algorithms. In the

above comparison, the finite-difference and the Laplace-transform algorithms were both iterated until a day/night surface-temperature difference of less than one degree was achieved between iterations. The Fourier-series algorithm requires the computation of a series summation but requires no iteration. The Laplace-transform algorithm requires twice as many iterations as does the finite-difference algorithm. The actual number of iterations depends upon the complexity of the boundary condition and the accuracy desired. Thus the relative ranking of the algorithms in increasing order of required computer time is the Fourier series, the finite difference, and the Laplace transform.

Another consideration in performing thermal-inertia mapping is the need to be able to see the relationship between various parameters and surface temperature. From a knowledge of such relationships, the importance of various parameters on the calculation of thermal inertia is seen. Only the Fourier-series solution (eq. 4) allows this awareness. For example, the form of the solution suggests a mean temperature level that is modulated by the amplitude and phase of the harmonic term. We can recognize that changes in the geothermal heat flux or changes in the emissivity will produce a shift in the diurnal temperature curves; changes in the albedo will result in changes in both the mean level and the amplitude of the diurnal temperature. Thus a day/night temperature difference, which is a measure of this amplitude, does not contain, to first order, the effects of sky temperature, geothermal flux, or the zero-order term of the insolation. A recognition of these and similar relationships led to Watson [1] developing methods for both thermal inertia-mapping and geothermal heat-flux mapping.

Table 2 summarizes the results of this section.

4. TOTAL SYSTEM ERRORS

Measurement errors introduced by the multispectral scanning system impose a fundamental instrumental limitation on thermal-inertia mapping. These errors are the result of a combination of factors, including the noise limit of the detector, amplifiers, tape recorder, and, for a satellite system, down-link telemetry. These errors are commonly expressed as noise-equivalent-temperature differences (NEAT). For an aircraft system, a typical value for a state-of-the-art system is 0.1K. A 1K NEAT is representative of a satellite system such as Nimbus III and IV; the HCMM (Heat Capacity Mapping Mission) satellite system may have a slightly lower NEAT. These values of uncertainty in temperature convert to approximately 15 TIU for the aircraft and 150 TIU for a satellite. These resultant errors are in addition to the errors introduced by the mapping technique and represent a fundamental limitation inherent to the technique.

An error common to mapping data with both aircraft and satellite is that produced in the process of registering images acquired at different times. Because of changes in the vehicle path and scanner orientation (pitch, yaw, and roll), a point on the ground will not have the same image coordinates at two acquisition times. Daytime images acquired at the same time are automatically registered with each other and are geometrically identical. These "matched" images are called image-pairs. The registration is performed by selecting reference features on a master image-pair and subsequently identifying those features on the remaining "distorted" image-pairs and on the nighttime thermal images. Reference features identified on both the master reflectance image and the master thermal image must be identified on the "distorted" nighttime thermal images but may be located on either the reflectance or the thermal image of "distorted" daytime image-pairs. The choice depends upon whether the appearance of the feature is governed by topography, thermal inertia, or reflectance. These reference features are then used as input to a triangular interpolation algorithm.

The errors due to misregistration are of two types. The first is a misregistration of an image-pair to the master image-pair. This misregistration results in an association of incorrect albedos and/or incorrect temperature-difference computation--both of which result in an inaccurate calculation of thermal inertia.

The second type of error is a misregistration of a calculated thermal inertia to a topographic map. This error is an inaccuracy in the assignment of a thermal inertia to a particular geographical point. We have not estimated the magnitude of these errors; however, we have qualitatively examined them.

Misregistration of either type results from one of two conditions: the spatial frequency of the misregistration is higher than the spacing of the reference features or the image features are not discernible enough to select suitable reference points. The first of these conditions--the rapidly varying scene--is correctable by choosing more frequent reference points, and the resulting errors in thermal inertia can be minimized. The additional points do impose a significantly higher computer time. The second condition--low scene contrast--is common especially in nighttime imagery. In such situations the best estimate of the location of a reference feature on an image-pair is made by scaling the distance from other identifiable features. In this case, the resulting registration may be geometrically inaccurate but numerically equivalent due to the resulting low contrast image, which will not exhibit much variation in temperature and/or reflectance values. Thus, these errors produced in computing or assigning thermal inertia are small. The edge effects that may be produced by identifying features by scaling can be reduced by spatial filtering.

In addition to the measurement errors, another important source of error in thermal-inertia mapping results from simplifications introduced by a particular model. These simplifications include the exclusion of transient fluxes, topography, and/or surface-coating effects.

Transient effects are those resulting from such conditions as cloudiness, windiness, or ground moisture. Effects of this type can be viewed as a flux perturbation on the periodic solution [11]. To illustrate this situation, we consider a heat-flux perturbation of 35 watts/m². The magnitude of this perturbation is equal to 2.5% of the solar constant, or an equivalent change in sky temperature of 10°K, or the effect of an evaporation rate of 1.4×10^{-8} m/sec (1.2 mm/day). The transient-effect calculation was made by varying the duration of the perturbation and noting the resulting change in surface temperature at a later time. A graph expressing the resulting errors in thermal inertia is presented in figure 1. The maximum error introduced by this perturbing flux is approximately 200 TIU.

Correctable topographic effects require an assumption as to the scattering law for the sloping surface and the need to neglect reradiation between adjacent surfaces. We shall assume that the surfaces are Lambert reflectors, and thus the local solar flux is proportional to the cosine of the angle between the surface normal and the solar radiation. In that case, an east or west slope to the surface causes a phase shift in the diurnal temperature curves, and a north or south slope to the surface produces a change in amplitude of the diurnal curves. A surface oriented in any other direction produces a combination of phase shift and amplitude changes. Both changes result in erroneous day/night temperature differences. Similarly, slope and surface orientation affect the reflectivity and can cause erroneous determinations of albedo. Both temperature and albedo errors contribute to an incorrect determination of thermal inertia. The magnitude of this error (using the Raft River parameter values) for a 10° slope facing southwest is approximately 350 TIU with the maximum error in thermal inertia occurring for a southwestern facing surface (figure 2).

Surface coatings change both the surface reflectivity and the diurnal temperature; hence they affect the apparent thermal inertia of geologic materials. We examined the thermal effect of a hematite coating over a half space, having the average thermal inertia of igneous rocks. Figure 3 shows the implied change in equivalent thermal inertia for various thicknesses of this layer [8]. For example a hematite layer of 10 millimeters will produce a change in thermal inertia of approximately 200 TIU. If the layer thickness is less than 1 millimeter, the coating is transparent in terms of thermal-inertia mapping but will be observable as an albedo difference.

Of the three simplification effects described, only the topography correction is at a stage of development to be incorporated into the thermal-inertia mapping. The local variations in the surface staining, vegetation cover, and surface roughness occur at a scale which precludes detailed modeling because that would require detailed knowledge of these effects at every point in the test site. We consider these types of effects occurring at a local scale irreducible for any practical use of remote-sensing techniques. Similarly, topographic effects in localized areas due to departure from Lambert emission, reradiation between adjacent surfaces, or shadowing effects are also probably in the same category.

5. DISCRIMINATION OF GEOLOGIC MATERIALS

In the previous sections, the types and magnitudes of errors encountered in performing thermal-inertia mapping were discussed. Now these errors are placed in geologic context and thereby provide criteria for evaluating the entire procedure. Thus the selection of modeling algorithm and data-collection procedure can be examined in the light of a particular geologic situation.

As an illustration, assume that we wish to discriminate between limestone and dolomite from a satellite in a study site that is relatively flat and whose outcrops have iron-oxide stains of approximately one-millimeter thickness.

<u>Error Sources</u>	<u>Error Magnitude</u>
satellite measurement	150 TIU
topographic effects	0 TIU
typical surface-coating effects	25 TIU
typical transient effects	100 TIU
	275 TIU

These measurement and model simplification errors are now combined with the analysis errors. The total system errors for each algorithm are:

<u>Algorithm</u>	<u>Approximate Total Error</u>
Fourier series	750 TIU
Finite difference	600 TIU
Laplace transform	550 TIU

We now know that we cannot discriminate between geologic materials having a thermal-inertia difference of less than 750 TIU using the Fourier-series or of less than 550 TIU using the Laplace-transform algorithm.

Figure 4 shows thermal-inertia histograms of various sedimentary rocks [12, 13]. From the histograms, we can determine that a typical thermal inertia for limestones is 2200 TIU and for dolomites is 3500 TIU; thus the separation is greater than the least accurate of the algorithms. Since any of the three analysis algorithms can be used, the selection of the algorithm will be determined by the cost/effectiveness criteria and the Fourier series would be selected.

In the hypothetical case, if we wish to discriminate between sandstones and dolomites, which typically have a thermal inertia separation of 550 TIU, we must select the Laplace-transform algorithm.

Table 3 shows typical thermal-inertia values for a range of igneous rocks. The separation between a fine-grained felsic rock (rhyolite) and a coarse-grained felsic rock (granite) is only 200 TIU; the separation between rhyolite and a coarse-grained mafic rock (gabbro) is approximately 400 TIU. Discrimination of a fine-grained felsic rock from a coarse-grained felsic rock can be achieved with the Laplace-transform technique, using many iterations and shortening the time interval. Discrimination of a fine-grained felsic rock from a coarse-grained mafic rock can be achieved with either the finite-difference algorithm or the Laplace-transform algorithm, depending first upon the measurement and model errors and second upon the cost/effectiveness.

In the analysis of Landsat data, discrimination between black shale and gabbro was not possible using spectral-reflectance data [2]. The thermal inertia separation of these two materials is approximately 450 TIU (Table 4), [9, 13] and the magnitude of the separation indicates that discrimination by thermal inertia is practical even by satellite. Discrimination among basalt, andesite, argillite, and black chert was also reported to be not possible by Landsat. Table 4 shows that thermal-inertia discrimination should be possible between black shale and gabbro, between basalt/andesite and black chert, and between argillite and black chert. Discrimination among argillite, basalt, and andesite does not appear possible.

Thermal inertia of soils is dependent primarily on bulk density and moisture content. Figure five shows that there is a rough linear relationship between thermal inertia and density for dry materials. The addition of moisture to dry soil results in a rapid increase in thermal inertia. For example, dry sand has a thermal inertia of 590 TIU, and wet sand (8% moisture) has a thermal inertia of 1020 TIU. Thus, for sand, the thermal-inertia mapping from aircraft (NEAT = 0.1K) has an accuracy of about 1% in bulk density, or equivalently a sensitivity of 0.3% in water content. From satellite (NEAT = 1K) these accuracies are 9% and 3% respectively.

6. RAFT RIVER ILLUSTRATION

The method of analyzing errors in terms of uncertainties in thermal inertia was then applied to an analysis of a thermal-inertia map constructed of an area of the Raft River, Id. Reflectance and thermal data were acquired at five different times in the diurnal cycle from July 24 to July 31, 1974. Figure six is the thermal image acquired near solar noon (July 31); figure seven is the thermal image acquired near solar midnight (July 31). These two images were used to form the temperature-difference image. Figure eight is the daytime reflectance image used to form the thermal-inertia map.

Geometrically registered albedo and day/night temperature-difference images were formed according to the procedure outlined in the section on total system errors. A relative thermal-inertia image (figure 9) was then constructed from the images by forming the ratio of albedo to day/night temperature difference. The scale on the side of the image that relates the gray scale to absolute thermal-inertia values was determined from the Fourier-series algorithm using a sky temperature of 245°K and a cloud cover factor of 0.13. The sky temperature and cloud cover factor were determined using a least-squares model fit to all the repetitive thermal-scanner data for the site. In the formation of this image, no correction for topography was made.

From the above information, the total measurement and analysis errors are compiled as follows:

<u>Errors</u>	<u>Magnitude</u>
Fourier-series algorithm	460 TIU
Aircraft measurement	15 TIU

Three geologic materials have been discriminated on the thermal-inertia image [10]: lava flows, tuffs, and alluvium (figure 9). Histograms were constructed of the thermal-inertia values of these materials from the map. The lava flows have a thermal inertia of 2010 ± 250 TIU; the tuffs have a thermal inertia of 1470 ± 210 TIU; and the alluvium has a thermal inertia of 1090 ± 80 TIU. From a topographic map, the alluvium was determined to be on a flat surface; the tuff area has a slope of 7.9° and an azimuth (measured counterclockwise) of 225° ; and the lava flows have a slope of 10° and an azimuth of 198° . Thus the error in thermal inertia due to topography is 0 TIU for alluvium, -95 TIU for tuffs, and +110 TIU for the lava flows. We therefore determined that we cannot discriminate the tuff from the alluvium and the lava without a topographic correction, but we can discriminate the lava flows from the alluvium.

7. SUMMARY

The utility of thermal-infrared surveys to discriminate geologic materials based on differences in their thermal properties has been recognized by previous investigators. The error analysis technique presented here provides the means to evaluate the validity and reliability of such discrimination. This technique also provides criteria for selecting the most cost/effective algorithm for a particular geologic application. In addition, it can be applied to determine the fundamental accuracy required, and thus whether aircraft or satellite (for example, HCMM) data would be appropriate. A parallel analysis technique could be developed for geothermal heat-flux mapping. Such a technique could express the various errors in terms of the minimum detectable geothermal heat flux.

Additional improvements in the mapping can be provided by incorporating a topographic correction into the model. One way of accomplishing this is to incorporate digital topographic data in a look-up table [6]. Another method would be to assume a reflection law and compute the topographic correction using three reflectance images. Additional refinements would include the addition of a diffuse illumination term in the insolation factor and a more detailed treatment of areal transient effects. In our treatment, the sky radiation and solar-transmission factor were assumed constant and were determined by a least-squares fit to the actual image data. A least-squares fitting including harmonic terms could be added to represent more accurately the actual areal transient effects.

This study--even with its assumptions and simplifications on the model--should provide a useful comparison of the errors encountered in thermal-inertia mapping. Most importantly, all the uncertainties in the mapping technique are described in the context of discriminating geologic materials.

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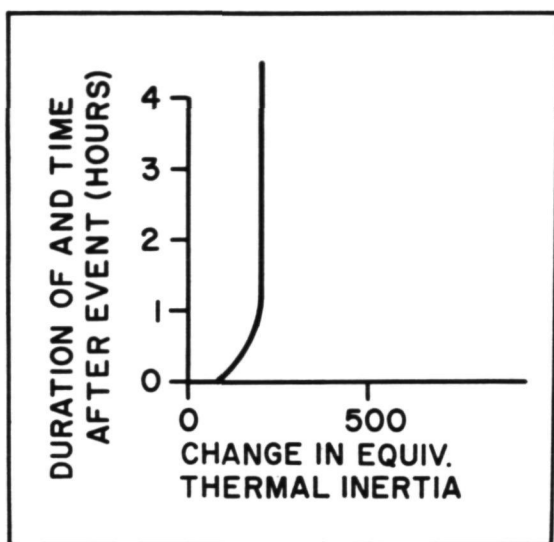


Figure 1.--Change in equivalent thermal inertia for a 35 watt/m² perturbing flux.

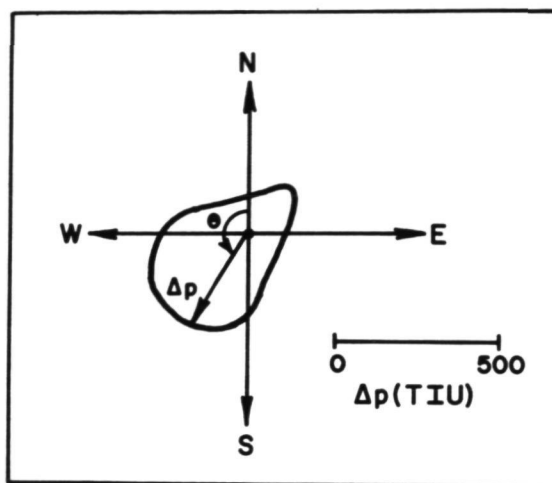


Figure 2.--Polar plot of change in equivalent thermal inertia for a 10° slope for variable azimuth angles (θ).

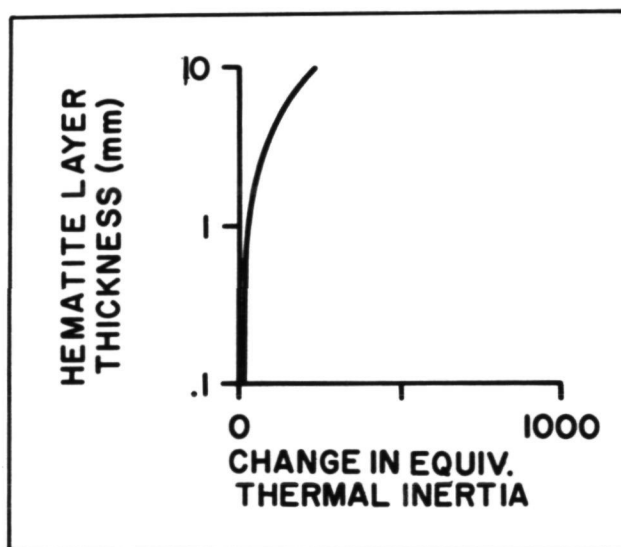


Figure 3.--Change in equivalent thermal inertia for a variable thickness hematite layer.

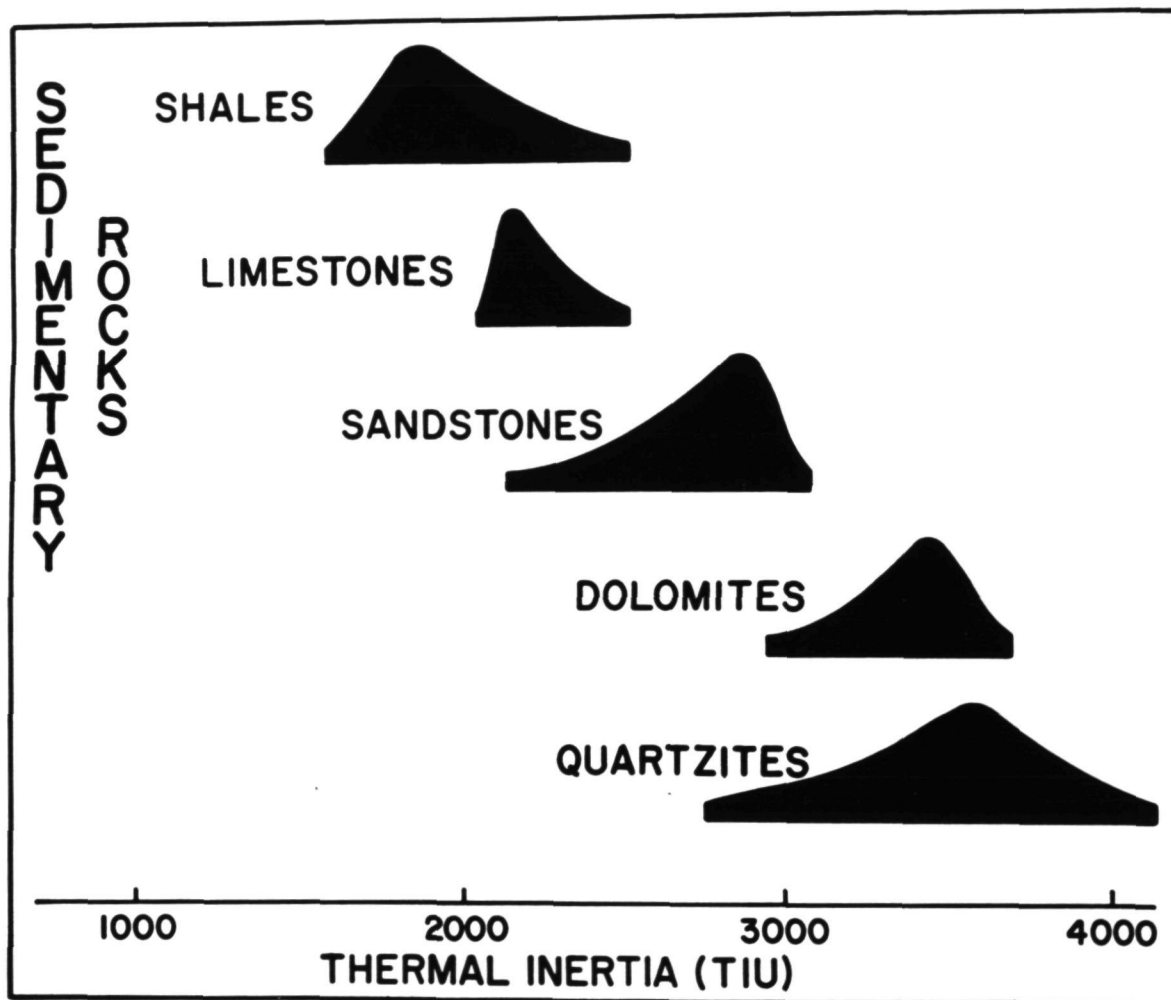


Figure 4.--Histograms of the range of thermal inertias for some sedimentary rocks [12], [13].

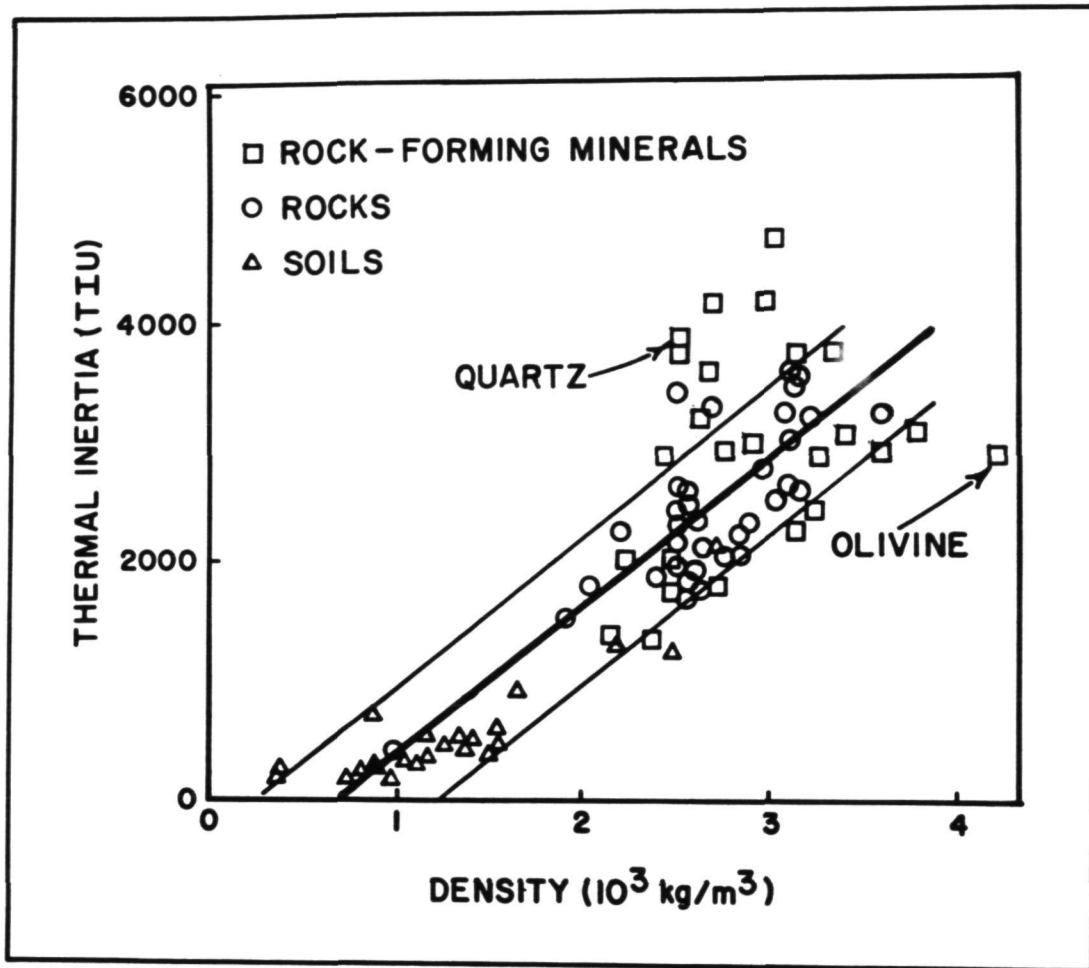


Figure 5.--Thermal inertia versus density for a variety of rock forming minerals, rocks, and soils.

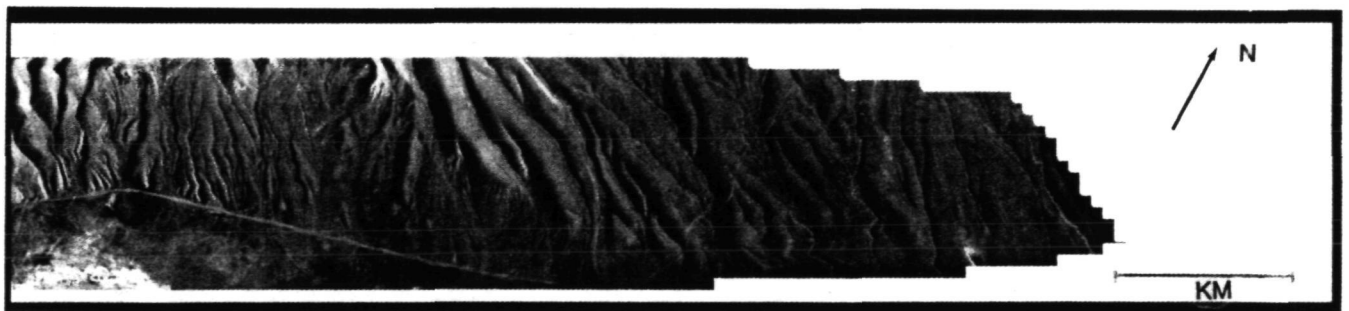


Figure 6.--Thermal image acquired at 1430 hours of an area of the Raft River, Id., July 31, 1974.

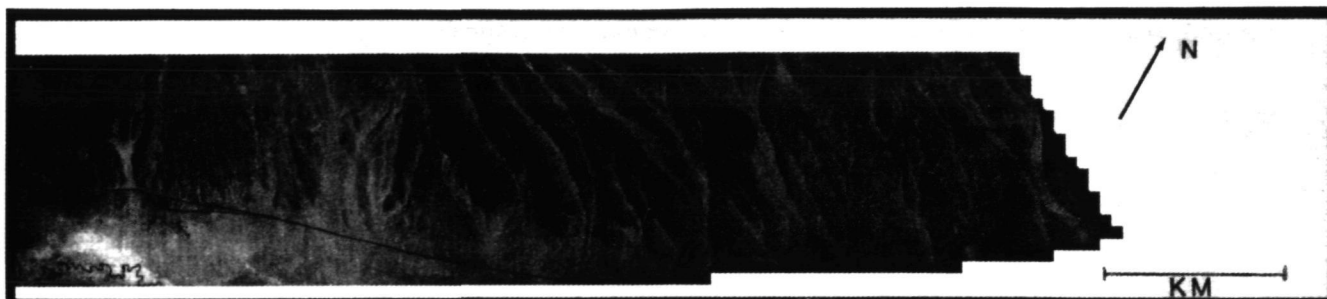


Figure 7.--Thermal image acquired at 2300 hours of an area of the Raft River, Id., July 31, 1974.

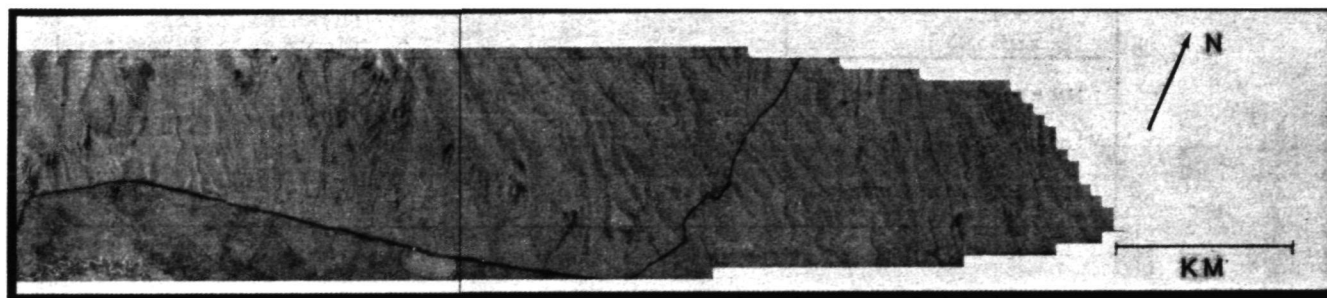


Figure 8.--Reflectance image acquired at 1430 hours of an area of the Raft River, Id., July 31, 1974.

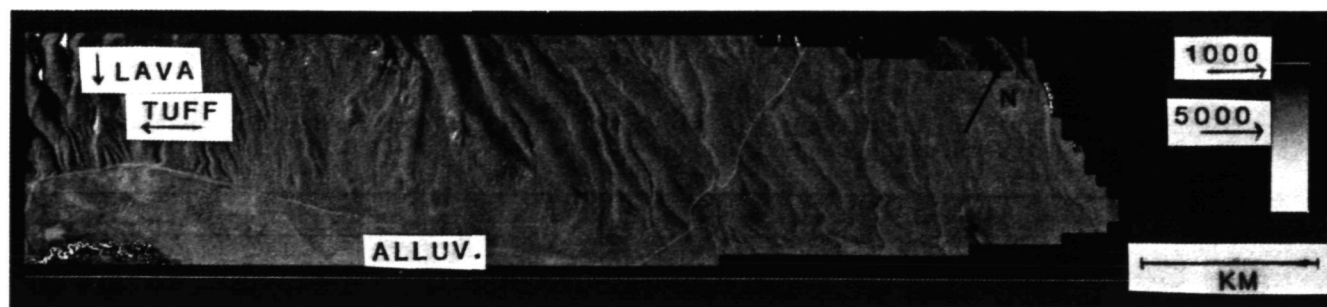


Figure 9.--Thermal-inertia map created from the 1430 and 2300 hours thermal image and a 1430 reflectance image of an area of the Raft River, Id.

TABLE 1. Parameter values used to compare the three algorithms.

$F_0 = 475 \text{ watts/m}^2$
$T_{\text{sky}} = 260^\circ\text{K}$
$\epsilon = 1.0$
$\Delta t = 8640 \text{ sec (0.1 day)}$
$\Delta x = 0.12 \text{ m}$

TABLE 2. Relative ranking of algorithms with respect to cost/effectiveness.

<u>ALGORITHM</u>	<u>CRITERIA</u>		
	Accuracy	Computer Time	Visualizing Physical Significance of Parameters
Linear Fourier Series	Least	Least	Yes
Finite Difference	Median	Median	No
Laplace Transform	Most	Most	No

Table 3. Typical thermal-inertia values for a range of igneous rocks.

<u>ROCK TYPE</u>	<u>THERMAL INERTIA (TIU)</u>
Rhyolite	1950
Granite	2150
Basalt	2200
Gabbro	2350

Table 4. Typical thermal-inertia values for some geologic materials that were studied using Landsat data [9, 13].

<u>ROCK TYPE</u>	<u>THERMAL INERTIA (TIU)</u>
Black Shale	1900
Gabbro	2350
Basalt/Andesite	2200
Argillite	2250
Black Chert	3100

USE OF THERMAL-INFRARED IMAGERY IN
GROUND-WATER INVESTIGATIONS IN MONTANA

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ABSTRACT

Thermal-infrared imagery was used to locate ground-water inflow along three streams and one lake in Montana. The thermal scanner used in May 1972, March 1973, and November 1975 was mounted in a twin-engined aircraft. On the 1973 and 1975 flights, the data were recorded in an analog format on magnetic tape in flight, later were converted to digital format, and were computer-processed using an assignment of patterns to indicate differences in water temperature. Output from the image-processing program was converted to a temperature map having an isotherm spacing of 0.5°C. Computerization was found to be the most efficient method to manipulate data from lakes, large rivers, and narrow sinuous streams.

1. INTRODUCTION

Thermal-infrared sensors enable the hydrologist to detect dispersion and circulation patterns and ground-water discharge in various-sized bodies of water. This information is useful in locating water having desirable fish-rearing characteristics, locating areas of potential water-quality changes, and locating routes of industrial effluents (Whipple, 1972; Pluhowski, 1972).

The purpose of this investigation was (1) to determine if ground-water inflow to lakes and large rivers in Montana could be detected by the use of thermal-infrared imagery, (2) to test the usefulness of computer storage, retrieval, and processing of the data, (3) to demonstrate a useful format for presenting the data, and (4) to determine the usefulness of thermal-scanner data on a narrow sinuous stream.

2. THE THERMAL SCANNER

Temperature data were collected by using a thermal-infrared scanner mounted in a twin-engined aircraft capable of flying 345 km (kilometers) per hour. The scanner has a total field of view of 120°, two black-body calibration sources, and an accuracy of 0.2°C (Celsius) (Boettcher, and others, 1976). The flights were between 455 and 760 m (meters) above the water surface during predawn hours. The 8.5- to 11-μm (micrometer) range of the scanner was used to detect water temperatures.

Data output from the scanner were recorded on film, and during two flights on magnetic tape also. The film was processed in flight by a two-step rapid processor as it was exposed. Thermal data from the scanner, data from the aircraft gyro system, mileage data from the aircraft doppler system, and a voice

track of the crew describing geographic locations were recorded on a fourteen-channel magnetic tape.

3. THERMAL-SCANNER EXPERIMENTS

The thermal-scanner experiments were made as part of ground-water investigations conducted in Montana by the U.S. Geological Survey in cooperation with the Montana Bureau of Mines and Geology, Bonneville Power Administration, and Environmental Protection Agency. Imagery was obtained along the Kootenai River and Lake Koocanusa in northwestern Montana, along the Clark Fork of the Columbia River near the Idaho-Montana State line, and along the Tongue River near the Wyoming-Montana State line (Fig. 1).

3.1. KOOTENAI RIVER AND LAKE KOOCANUSA

On May 17, 1972, a flight of about 80 km was made along the Kootenai River as shown by the hachures on figure 1. The purpose of this flight was to determine (1) if ground-water inflow could be detected by using an airborne thermal scanner, (2) if ground-water temperature plumes could be distinguished from other temperature plumes in lakes, and (3) what range of temperature calibration would be necessary to obtain maximum contrast on the film showing water.

The flight was made when the tributaries of Lake Koocanusa and the Kootenai River contained snowmelt runoff having temperatures of about 5° to 7°C. A temperature differential is apparent on figure 2A, where the measured temperature of the water in the forebay of Libby Dam was 12°C and the temperature of the water in the Fisher River was 7°C. Figure 2B shows a plume of warmer ground water flowing into Lake Koocanusa from an alluvial fan. Water temperatures not affected by ground water can be seen west of the alluvial fan. The temperature difference from black to white on the images is 7°C (from 5° to 12°C), as calibrated on the scanner. This range in temperature produced the maximum contrast.

3.2. CLARK FORK OF THE COLUMBIA RIVER

On March 29, 1973, a flight was made over the Clark Fork of the Columbia River as shown by the hachures shown on figure 1. The purpose of this flight was to (1) determine if ground-water inflow into a large river could be detected by thermal-infrared scanning techniques, and (2) if scanner data recorded on magnetic tape could be enhanced better by computer than by film.

In this reach of the Clark Fork, a deep narrow valley has been eroded into argillite and quartzite of the Belt Supergroup of Precambrian age and partly filled by highly permeable alluvium. Water flows into the alluvium from Noxon and Cabinet Gorge Reservoirs, then downvalley through the alluvium, and reenters the Clark Fork a short distance below the dams. From 28 to 71 m³/s (cubic meters per second) of inflow from the alluvium has been measured below Noxon Rapids Dam.

The warmer (white) ground-water inflow below Cabinet Gorge Dam can be seen along the left bank of the Clark Fork (fig. 3). Imagery of this area was used to test computer techniques because temperature differences were large in a small area. Small amounts of ground-water inflow would probably be masked by the large quantities of colder river water.

The scanner data were recorded on magnetic tape and converted to digital format. Each number represented the thermal emission from a ground-resolution cell size of about 1.5 m by 0.38 m. A digital image having a ground-resolution size of 1.5 m x 1.5 m was prepared by using every fourth row of data.

Automatic generation of the contours of only the river, required that the digital image be masked, setting to zero areas of land surface and leaving any pixel (picture element) that was water. Then, any pixel having a value of zero and being within a distance of 8 resolution cells of a non-zero pixel, was set to the value of its closest non-zero pixel. This operation in effect extended the boundary of the river.

After the boundary was determined, an averaging technique was used to smooth the image. The smoothed image was then masked with the same mask that had been used to select only water pixels. This masked to zero any pixels composed of averages of water pixels and zero-valued pixels.

To obtain some number, N, of contour levels, the resulting image was equal-interval quantized to N levels. The contours were computed by testing each pixel to determine whether it was a boundary pixel. A boundary pixel is not equal in value to at least one of its four nearest neighbors. Any boundary pixel which had the highest value of its four neighbors was labeled as a contour pixel and assigned its quantized value. All other pixels were set to zero.

The maximum temperature of a mixture of ground-water inflow and river water was 8.5°C, whereas the river water was predominantly at 6.0°C (fig. 4). The stream-bank temperature was 5.5°C. Figure 4 is a computer version of the temperature changes caused by ground-water inflow. The isotherm interval is 0.5°C. The 5.5°C temperature is denoted by zeros and the 8.5°C temperature by 6's. The isotherms were drawn manually; however, they could have been drawn on a plotter. The computer output showed the sizes and locations of the anomalous plumes more distinctly and quantitatively than the film output.

3.3. TONGUE RIVER

On November 19, 1975, a 156-km flight was made over a reach of the Tongue River as shown by the hachures on figure 1. The scanning started at Tongue River Dam which had been closed for repairs for twenty days before the flight, thus affording an opportunity to measure ground-water inflow. About 0.6 m³/s of water was pumped over the dam to maintain flow for aquatic life.

The purpose of this flight was to (1) determine if ground-water gains to the stream could be detected by thermal-scanning techniques, and (2) determine if inflow to a narrow sinuous stream having low flow could be detected using computer techniques and thermal-scanner data.

In this reach of the Tongue River, the valley has been eroded into the Tongue River Member of the Fort Union Formation of early Tertiary (Paleocene) age. The Tongue River Member consists of sandstone, siltstone, coal, and shale. The valley is about 1 km wide and is partly filled by silt, sand, and gravel from 21 to 30 m thick.

Weather conditions significantly affected streamflow and the timing of the flight. Minimum air temperatures were below freezing for about 2 weeks before the flight, causing the river to be partly covered by ice that periodically melted. On the day of the flight, most of the shore was covered with ice and ice was floating in parts of the river. The river was flown on November 19 because that was the first day in nearly a week that the Tongue River valley was free of clouds.

The scanner data were recorded on magnetic tape and later digitized for computer use. To prepare the river temperature graph to map scale, the digitized-image data were geometrically corrected. The digital image was displayed on a viewing screen and an electronic pointer was used to select the river points whose temperature was required. The program converted the position on the viewing screen to a row/column coordinate on the digitized image and the value of the pixel in the specified row/column position was recorded. The digitized values were converted to temperatures by linear scaling. The coefficients of the scaling were determined from ground-truth data.

The computer output (fig. 5) shows temperatures of the river at selected locations. At each location an "X" is placed on the printout and the temperature in degrees Celsius is printed on the same line at the right of the printout. The approximate configuration of the river was taken from topographic maps. The numbers along the river are locations where streamflow measurements were made.

Figure 6 shows the longitudinal profile of water-surface temperature and discharge in the river. Increases in temperature through the short reaches are believed to indicate ground-water inflow because the ground water was warmer than either the air or the surface water. The lower temperatures could result from the water flowing through shallow reaches of the stream, or be due to melting ice. Weather conditions during the flight were not ideal because ice was melting, which decreased stream temperature and increased discharge. Below Station 12 the temperature of the river decreased greatly, because of melting ice.

The infrared imagery helped delineate specific reaches of the Tongue River that were receiving ground-water inflow. Computer techniques developed during this investigation to enhance the imagery appear to have wide application, especially for narrow streams. The techniques may also prove useful in the detection and documentation of changes in water temperature caused by man's actions.

4. CONCLUSIONS

Ground-water inflow to streams and lakes was observed from an aircraft-mounted thermal-infrared scanner. However, detection of small amounts of ground-water inflow to a sizeable river is difficult. Computerization is the most efficient and accurate method to enhance and manipulate scanner data. Large amounts of nearly error-free temperature data can be stored and retrieved by a computer. Additionally, items such as map-scaling factors and ground-truth data can be entered into the computer system to insure uniform temperature calibration. The computer output can be made to overlay most map scales; therefore, the combination of obtaining data by the thermal scanner and processing it by the computer appears to have wide application. The success of techniques developed during these investigations to enhance thermal-infrared imagery has proven their wide application to the study of lakes, large rivers, and narrow sinuous streams.

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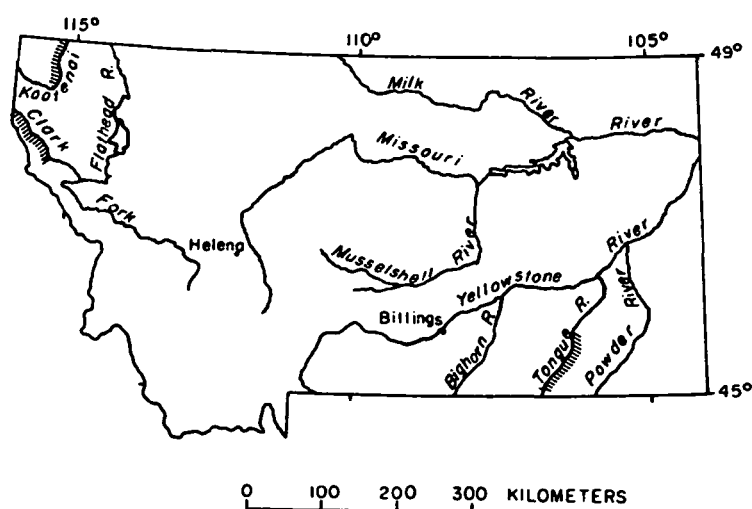


FIGURE 1. INDEX MAP SHOWING AREAS OF INVESTIGATION.

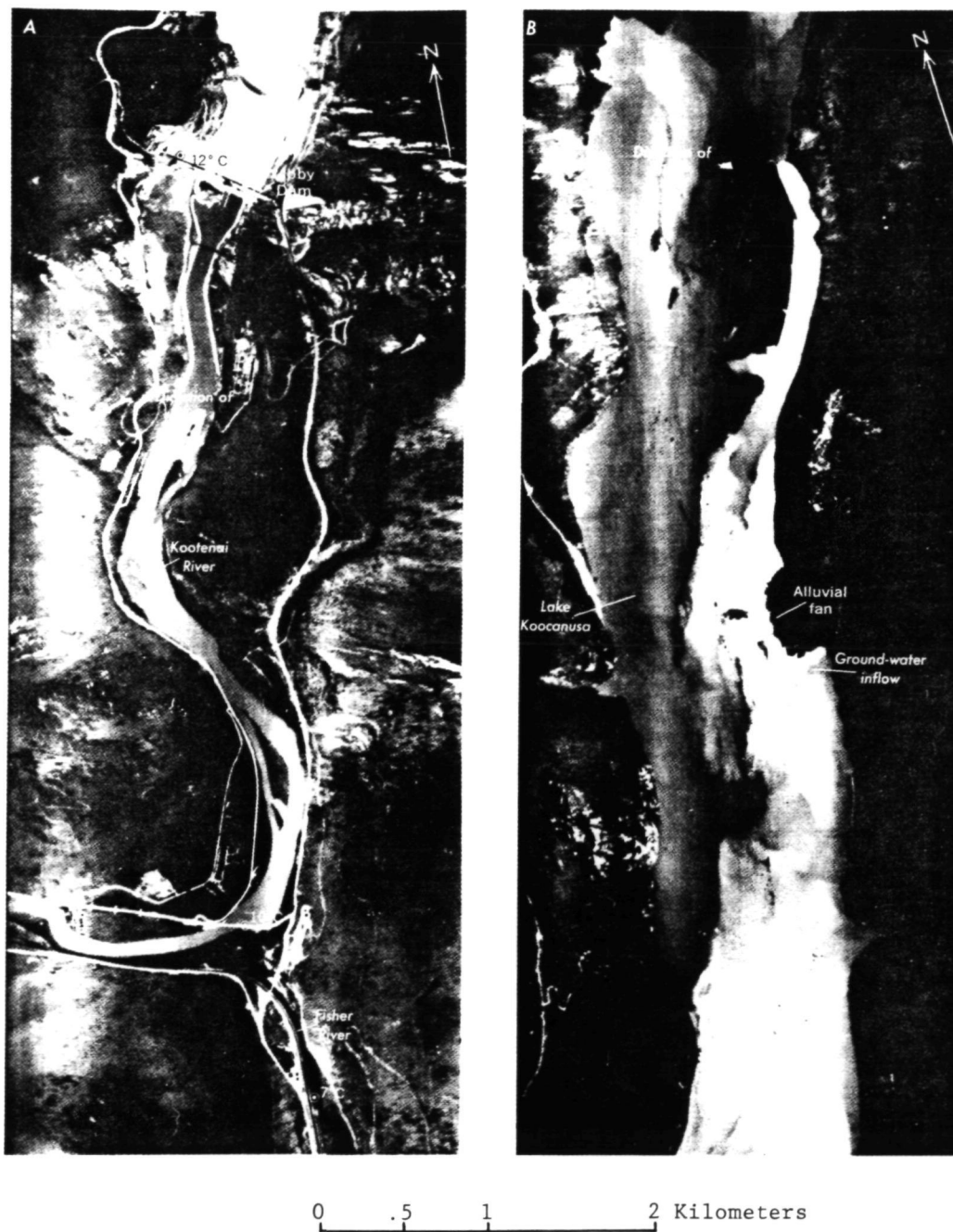
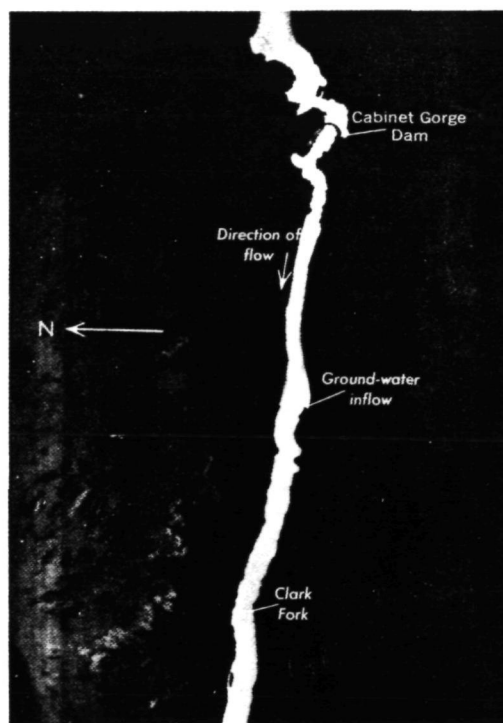


FIGURE 2. THERMAL-INFRARED IMAGERY AROUND LAKE KOOCANUSA.
A. Libby Dam and the confluence of the Fisher and Kootenai Rivers.
B. Ground-water inflow to Lake Koocanusa.
Imagery by U.S. Forest Service

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0 .5 1 1.5 2 Kilometers

FIGURE 3. THERMAL-INFRARED IMAGERY BELOW CABINET GORGE DAM.
Imagery by U.S. Forest Service.



FIGURE 4. TEMPERATURE DATA COMPUTERIZED.
Isotherm interval is 0.5°C .

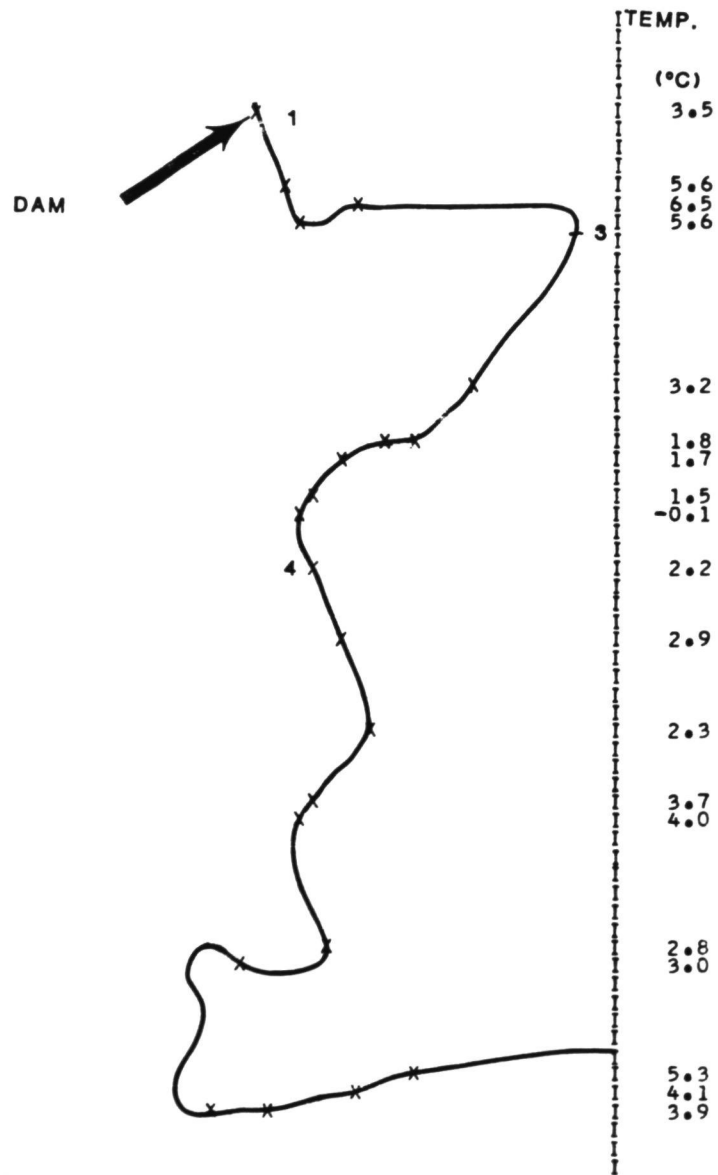


FIGURE 5. TEMPERATURES AT SELECTED LOCATIONS ALONG THE TONGUE RIVER.
Temperatures detected by thermal-infrared imagery (Nov. 19, 1975).

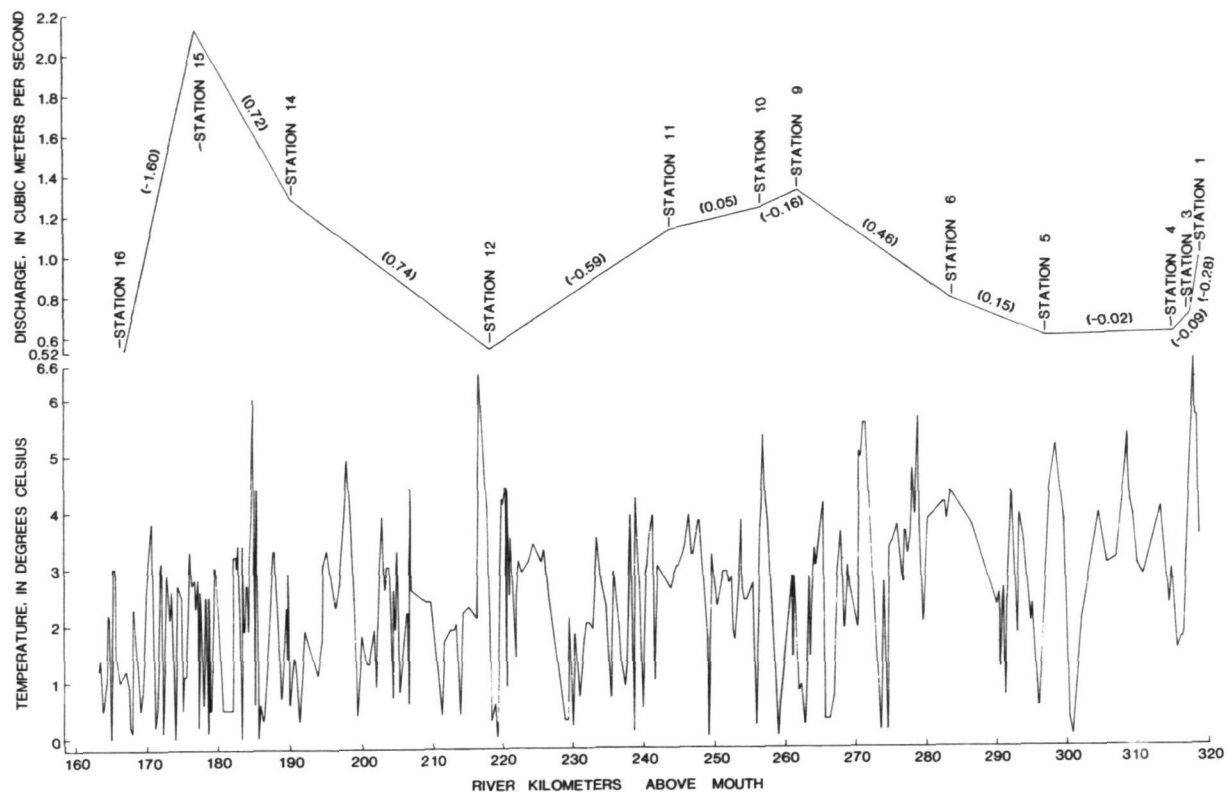


FIGURE 6. TEMPERATURE AND DISCHARGE OF THE TONGUE RIVER ABOVE THE MOUTH.
Numbers in parentheses indicate a gain or (-) loss.

SATELLITE LAND USE ACQUISITION AND APPLICATIONS TO HYDROLOGIC PLANNING MODELS

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ABSTRACT

In this paper, we report on a developing operational procedure for use by the Corps of Engineers in the acquisition of land use information for hydrologic planning purposes. The operational conditions preclude the use of dedicated, interactive image processing facilities. Given the constraints, an approach to land use classification based on clustering seems promising and is being explored in detail. The procedure is outlined and examples of application to two watersheds given.

1. HYDROLOGIC ENGINEERING PLANNING MODELS

The objective of our work is to develop operational procedures for use by the Corps of Engineers across the United States in the acquisition of land use information. The primary source of data is LANDSAT digital data and the intended use of the land use information is for hydrologic planning purposes. Land use information allows the Corps of Engineers to assess the flood hazard, general damage potential, and environmental status of watersheds. Use of this information is illustrated in a recently completed pilot research Flood Plain Information (FPI) study [1] by the Hydrologic Engineering Center (HEC) of the Corps of Engineers. In the study, data management and analytical techniques, integrating the use of spatial gridded geographic data files (called Grid Cell Data Bank), are incorporated into hydrologic computer models denoted HEC-1 and STORM.

The analysis methods of the HEC study interpret the hydrologic, economic, and environmental consequences of alternative land use patterns in combination with other physical characteristics of the watershed, such as soil class, land slope, erosion index and topography. Land use information is the key factor in performing the analysis in that it is used as the primary indication of the watershed conditions and of its response to precipitation.

The acquisition of land use information by conventional methods such as manual classification using aerial photographs or ground surveys are often time consuming for large watersheds or inadequate, not providing accurate spatial information of land use. Remote sensing data can provide land use information accurately and in a timely fashion for hydrologic planning purposes. By proper use of high speed digital computers, highly accurate and point-by-point information of land use can be extracted from the remotely sensed data.

2. LAND USE CATEGORIES AND REMOTE SENSING FOR HYDROLOGIC APPLICATIONS

Since the land use pattern is an important factor in hydrologic, economic and environmental analysis, the development and use of a reasonable set of land use categories is quite important. Hardy and Anderson [2] have recommended a standard set of land use categories for use with remote sensing data. Ragan [3], in applications to water resources, has used a modified subset of land use categories* of Hardy and Anderson, and has shown that remote sensing

*Land use categories used by Ragan in his work are: Forested area, highly impervious, grassed area, residential, streets and highways, bare land, streams, ponds or pools.

data can provide land use information. The land use pattern was then used by Ragan to determine hydrologic parameters in urban hydrology.

On the other hand, we note that the FPI study by HEC has applications to economic and environmental analysis as well as to hydrology. Thus, the objectives and criteria which determine a set of land use categories in this study are different from what was used in previous work. Quoting the criteria applied by HEC to determine a rational set of land use categories:

- " • The categories should be reasonably compatible with local and other agency land use classification schemes
- It must be reasonably possible to classify the land use within the study area by conventional or automated means
- The land use categories should allow rational, consistent determination of flood hazard, economic and environmental effects of land use change
- The land use categories should be compatible with those needed by certain available computer models
- The land use categories should provide a complete umbrella of classifications so that further breakdown of land use within each category would be possible if deemed necessary in future studies"

The different concerns in land use for each application are well expressed in another quotation from the HEC report:

" ... from the hydrologic viewpoint, the concern in a land use sense is with moisture retention/precipitation excess and basin response characteristics which are related to impervious cover and land surface management measures. From the economic viewpoint the damage potential and disruption of community activities is a function of urban development in general and the size, density, and type of structures and contents. From the environmental viewpoint, the concern is mostly with the intensity of development and the potential for adverse impacts (such as pollution) that could derive therefrom."

In the specific application of the FPI study to the Trail Creek Watershed in Georgia, HEC has adopted the set of land use categories shown in Table 1. These categories represent a compromise between the general criteria mentioned above and the technical requirements needed for applications to hydrology and economic and environmental studies.

Note that, for the economic and environmental analysis, detailed land use information in urban areas is quite important, which is not the case for hydrologic analysis. The requirements of accurate urban land use classification, such as differentiation between commercial and industrial areas, and differentiation of housing density of residential areas, are quite difficult to meet from remote sensing data.

3. OUTLINE OF AN OPERATIONAL PROCEDURE

Since the final operational procedure should be easily applicable by the field engineers of the Corps of Engineers, this precludes the use of any dedicated and highly interactive image processing hardware (such as G.E. Image 100 or the Bendix M-DAS System). The procedure should require only a limited number of iterations and not rely on the use of full scale color image display. The emphasis is thus in the use of general purpose computers and line printers for intermediate and final output products.

With these specific objectives and constraints, we have first tried a maximum likelihood classification algorithm to determine whether it can be adapted into an operational procedure. We have encountered several difficulties in using a maximum likelihood classifier. Among these are: (1) The choice of land use categories on which the classifier will be trained: The set of land use categories should be complete in the sense that every part of the watershed should belong to one of these categories. We have found the selection of land use categories difficult. (2) Training areas: To have a reliable estimate of statistics, a

large number of sample points (corresponding to large size training areas) is required. In actual applications, it is not easy to find training areas of large size for certain land use categories (principally in urban areas). Further, the determination of the exact outlines and coordinates on the LANDSAT image for each training field is also difficult in the absence of an interactive color image display.

These difficulties make a maximum likelihood classifier unattractive or impossible as an operational procedure with a minimum amount of interaction. Unsupervised classification algorithms appear to be more suitable to our objectives. The clustering approach is a well known unsupervised classification algorithm, which does not require a priori knowledge of land use categories nor locating training areas. At this stage of our work, we are exploring in detail an operational procedure for satellite land use classification based on the clustering approach. The steps and sources of data for the proposed operational procedure are as follows:

a. Digital Specification of the Watershed. Information on the watershed obtainable from maps, such as the watershed boundary and major roads, is entered on a grid oriented data base using an x-y digitization tablet or by key punching the data on cards.

b. Preprocessing of the Data. The original LANDSAT data is transformed using a principal component or Karhunen Loeve (KL) transformation. Only two of the transform components are required for classification and this step results in a reduction in computing costs. This step is optional and can be bypassed for a small watershed.

c. Clustering. We have implemented and tried a clustering program based on the ISOCLS package developed for NASA Johnson Space Center.

d. Classification. The data is classified after clustering by labeling each cluster as belonging to one of the land use categories. This requires ground truth information in the form of maps and aerial photographs. After examining all the available information such as the display of the centers of resulting clusters, maps, and aerial photographs, one of the following decisions is made for each cluster: (1) The cluster belongs to a specific land use category. (2) It is a mixture of two or more land use categories or the information at hand is not sufficient to label the cluster, i.e., the cluster is either in conflict or inconclusive in nature. (3) The cluster is of no importance or not valid. We assign that cluster to an "other" category (none of the desired land use classes). The ground truth information such as maps and aerial photographs is used to label the clusters in the following manner. From the examination of the computer printout of clustering results, several spatially contiguous areas (each having more than M points) within each cluster are chosen and the corresponding LANDSAT data is brought in registration with maps and aerial photographs. By studying corresponding areas on all available data we make one of three decisions for each cluster as outlined above. We can also use the reverse process, i.e., define some ground truth points or areas on maps and photographs, and transform those points or areas to LANDSAT image coordinates. We can then label the data clusters. The registration procedure of maps, aerial photographs and LANDSAT data will be discussed later.

e. Reclustering. For the points belonging to the second group of clusters, i.e., clusters in conflict or inconclusive, a reclustering step is applied. First, points belonging to this group are selected from the original LANDSAT data; then the clustering algorithm is applied again to those points. The purpose of this reclustering is to more finely subdivide the data in the difficult areas to allow unequivocal labeling of clusters. After reclustering, all the resulting clusters are labeled using the procedures described in Step d, with the only difference that we now try to label all clusters. Clusters which cannot be labeled properly are assigned to the "other" class. However, we expect that very few points will belong to this group. A schematic diagram showing the steps above is given in Figure 1.

f. Geometric Correction and registration of Maps, Aerial Photographs and LANDSAT Data: Geometric correction, using principally a least square geometric correction program requires that a number of control points be obtained from all the sources of data and entered in numerical form into a program. Obtaining such ground control points for LANDSAT data is an important problem which remains to be solved for the case in which no high quality, high resolution display of LANDSAT data is available. Alphanumeric printouts of portions of raw LANDSAT data which accentuates landform information is being considered as a possible source of ground control points.

4. PILOT STUDY

The operational procedure described above was applied to two watersheds of different size and geographic location; the Trail Creek Watershed in Georgia and the Castro Valley Watershed in California. Here we explain the results to date.

4.1. TRAIL CREEK WATERSHED

The Watershed is located in Clarke County and in the city of Athens, Georgia. It is relatively small, approximately 30 square kilometers and has been further subdivided into 21 subbasins in an HEC study.

Because of the need to establish a basis of comparison on pixel by pixel for our work using satellite data, we proceeded to do a manual classification of the land use in the watershed using NASA Research Aircraft images (Scene ID 6274 000 50047, 74/4/24). The manual classification serves as a principal basis for the verification of remote sensing classification results. Results of the manual classification are displayed in Figure 2. A tabulation of the percentage of each land use class is shown in Table 2.

4.1.1. MAXIMUM LIKELIHOOD CLASSIFICATION

In order to test the suitability of well developed classification algorithms, we first examined a maximum likelihood classifier. A particular version of LARSYS program was chosen primarily because of its availability and because of the well established application of maximum likelihood classifiers in agricultural land use classification [4].

We have attempted to classify an October scene (Scene ID 8180415322, 74/10/5) of the LANDSAT image of the Trail Creek Watershed using a maximum likelihood classifier. The steps in the classification procedure are: (1) Define a reasonable set of land use categories, (2) locate one or several training fields for each class on LANDSAT imagery and identify the coordinates of each training field, (3) run the classification program, and (4) process the result for display and tabulation. The classification result is displayed in Figure 3 and summarized in Table 2, along with other results.

4.1.2. CLUSTERING APPROACH

As explained previously, we encountered difficulties in the use of the maximum likelihood classifier, such as the choice of land use categories and defining training areas.

Considering these difficulties and our objective to develop an operational procedure with a minimum amount of interaction, we shifted emphasis from supervised to unsupervised classifiers. The clustering approach to land use classification is based on classifying first the data into machine classes or clusters according to machine measure of homogeneity without injecting into the process the human preconception of what the land use categories should be. Then a human being interacts with the machine to interpret and refine the results of the machine classification. At this second stage, the prior knowledge of land use and the relative importance of achieving accurate classification results for each land use category play an important role.

We have used the clustering approach for the Trail Creek Watershed. The same October scene used in the maximum likelihood classification was used again. The procedure used for our pilot study consists of the following steps:

(1) Principal component transformation of the data. The original LANDSAT image is transformed for data compression using the Karhunen Loeve transformation.

(2) Clustering of the data. The first two components of transformed data KL1 and KL2 are clustered. A display of the centers of resulting clusters are given in Figure 4.

For the purpose of comparison, we tried to label all clusters with land use categories as best we could without using the reclustering step. The result of the classification is summarized in Table 2, and designated "one step clustering."

(3) Initial classification. As described in step d of the operational procedure, we divide the clusters into three groups, shown also in Figure 4.

(4) Reclustering. For the clusters marked "reclustering" in Figure 4, we applied the

clustering program again using a different set of parameters. The final result of steps (3) and (4) are shown in Figure 5 and Table 2.

The result obtained by this operational procedure can be compared to the ground truth and to the maximum likelihood classification result. Even though clustering is significantly better than maximum likelihood classification, improvements might not be as apparent in direct numerical comparison of percentage of land use in each class, since generally numerically compiled results are the average of many detailed effects. However, the following conclusions seem justified.

(a) The clustering approach results in a significant improvement over the maximum likelihood classification when we examine the detailed classification point-by-point on an image.

(b) The clustering approach is much more flexible in the sense that the classes are assigned after the fact.

(c) Reclustering result is a significant improvement over the one step clustering classification.

(d) It still appears to be necessary to devise some kind of consolidation program to remove extraneous and isolated misclassified points.

Note also that we have used finally, only 6 land use categories instead of the 10 categories used by HEC. The following comments are pertinent:

(a) The separation of industrial and commercial classes. These two categories may not be differentiated accurately from remote sensing data. By applying a spatial consolidation algorithm, a partial success appears possible. For example, in clustering, we have a good indication that downtown commercial areas and large size parking spaces around shopping centers may be identified. Further work is needed.

(b) Density of residential areas. That depends largely on the definition of low, medium and high density residential areas. Residential areas, generally, tend to be clustered as newly developed or old residential areas on the basis of surroundings rather than housing density. More work on fairly large urban areas is needed to determine whether density of residential areas can be determined by using remote sensing data.

(c) Separation among agricultural, pasture and developed open space. We have not paid too much attention to this problem as yet. Even with lots of care and attention, it seems difficult to separate these classes even from high-flight images.

4.2. CASTRO VALLEY WATERSHED

Because of our interest in developing techniques useful in all parts of the country and because of the need to firm all details of the procedure, we are working on several watersheds across the United States. We are completing work on the Castro Valley Watershed in the San Francisco Bay Area. The Castro Valley Watershed is very small (12.8 sq. kilometers) and highly urbanized. It has been studied in great detail by the Corps of Engineers. We have applied the operational procedure based on the clustering approach and conducted also classification by photo interpretation using aerial photographs backed up by a ground visit to Castro Valley. On the basis of results to date, we are able to classify this watershed into six different classes and with an accuracy comparable to what was achieved for the Trail Creek Watershed. Shadows are much more pronounced in the Castro Valley Watershed and may result in classification problems.

5. DISCUSSION

We feel that we are developing a technique which should be usable operationally and we are trying to finalize the procedure so that the Corps of Engineers can use it with only line printer output. We are also planning to study in the coming few months 2 to 4 additional watersheds of different sizes (ranging from 250 to 750 square kilometers) and of different terrain across the United States to determine the applicability of the operational procedure to different geographic conditions and to different constraints on availability of data.

In order to make the operational procedure complete, there are several remaining problems to be solved. First, we need to improve classification accuracy within urban land use classes.

This problem appears to be difficult to solve perfectly and seems to be the major challenge for future work and possibly for higher resolution sensors. We also expect to encounter problems for large size watersheds in terms of computation time. And last, but not least, we have a continuing problem of compiling the results. In order that the classification based on LANDSAT data be integrated into a Grid Cell Data Bank, the original LANDSAT pixels should be distorted, scaled and resampled. In spite of these remaining difficulties, we are hopeful that the procedure developed will be widely useful in the common situations where specialized interactive computing equipment is not available.

6. REFERENCES

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3. Ragan, R. M., T. J. Jackson, et. al., "Use of LANDSAT and High Altitude Aircraft Remote Sensing in Urban Hydrology," Department of Civil Engineering, University of Maryland, College Park, Md., January 1976.
4. Fu, K. S., D. A. Landgrebe, and T. L. Phillips, "Information Processing and Remotely Sensed Agricultural Data," Proc. IEEE, Vol. 57, No. 4, pp. 639-653, April 1969.

7. TABLES

1. NATURAL VEGETATION
Heavy weeds, brush, scrub areas, forest woods
2. DEVELOPED OPEN SPACE
Lawns, parks, golf courses, cemeteries
3. LOW DENSITY RESIDENTIAL
Single Family: 1 unit per 1/2 to 3 acres; average 1 unit per 1-1/2 acres. Areal Breakdown: 5% structures; 10% pavement; 50% lawns; 37% vegetation. Proportion developed = 60%
4. MEDIUM DENSITY RESIDENTIAL
Single Family: typical subdivision lots; 1 unit per 1/5 to 1/2 acres; average 1 unit per 1/3 acre. Areal Breakdown: 10% structure, 15% pavement, 45% lawns, 30% vegetation. Proportion developed = 70%
5. HIGH DENSITY RESIDENTIAL
Multi-Family: row houses, apartments, townhouses, etc., structures on less than 1/5 acre lots; average 1 unit per 1/8 per acre. Areal Breakdown: 25% structures; 15% pavement; 35% lawns; 25% vegetation. Proportion developed = 100%
6. AGRICULTURAL
Cultivated land, row crops, small grain, etc.
7. INDUSTRIAL
Industrial centers and parks, light and heavy industry. Average 1 plant per 8 acres. Areal Breakdown: 20% pavement, 50% structures, 30% open space. Proportion developed = 100%.
8. COMMERCIAL
Shopping centers and "strip" commercial areas. Average 3 structures per acre. Areal Breakdown: Structures 30%, lawns 5%, vegetation 10%, pavement 55%. Proportion developed = 80%
9. PASTURE
Livestock grazing areas, ranges, meadows, agricultural open areas, abandoned crop land
10. WATER BODIES
Lakes, large ponds, major streams, rivers

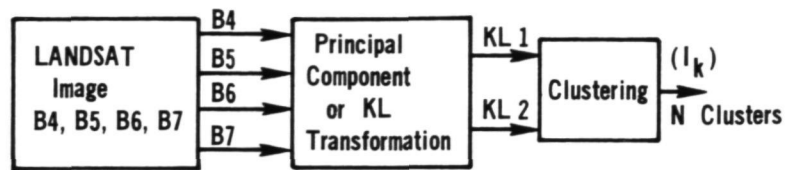
TABLE I. HEC LAND USE CATEGORIES, TRAIL CREEK WATERSHED

Land Use	Percent of Area			
	Ground Truth	Maximum Likelihood Classification	One Step Clustering	Operational Procedure
Natural Vegetation	50.17	36.19	48.69	45.06
Residential	(low density) 2.45 (medium density) 6.79 (high density) 0.11	23.78	16.60	15.31
Dev. Open Space	0.49	8.82		
Agricultural	28.73	19.17	26.69	32.24
Pasture	3.04			
Industrial	2.59	6.08		
Commerical	1.55	1.97	5.84	5.21
Water Bodies	0.57	1.02	0.97	0.97
Trailer Parks	2.47	2.98		
Highways	1.06			
Open Space			1.21	1.21

TABLE II. AREAL PERCENTAGE OF LAND USE AS DETERMINED FROM LANDSAT IMAGE - TRAIL CREEK WATERSHED.

8. FIGURES

Preprocessing and Clustering



Classification

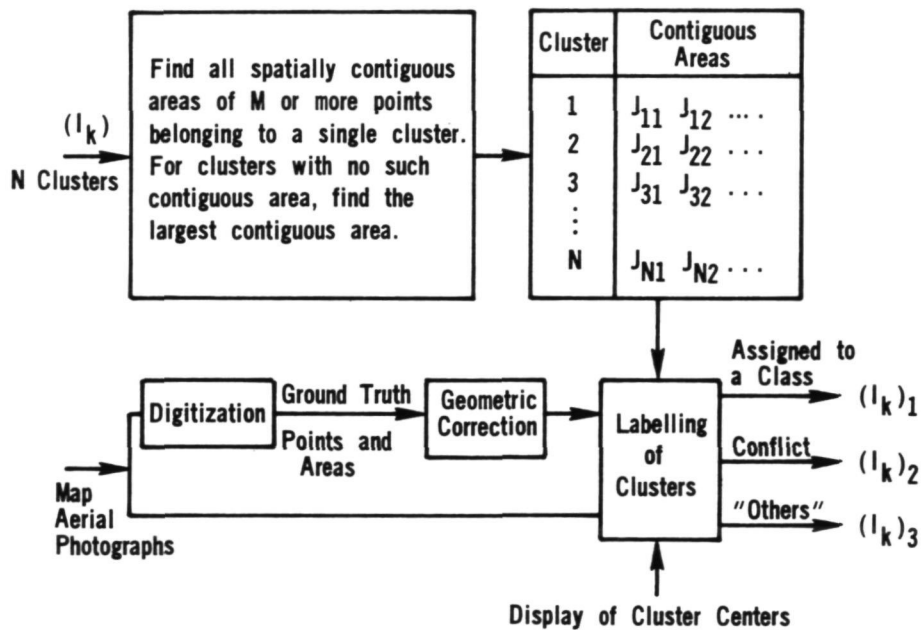


Figure 1. An Operational Procedure for Land Use Classification.

Reclustering

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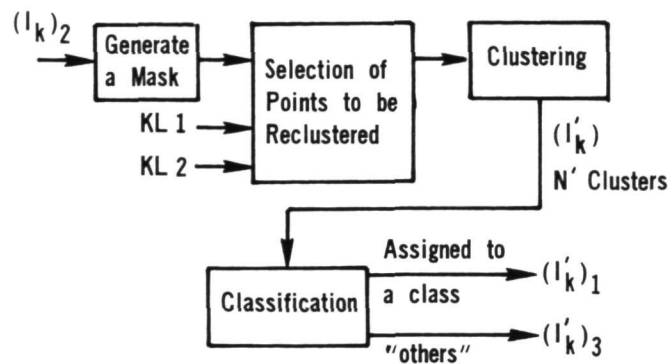


Figure 1. (Cont.)

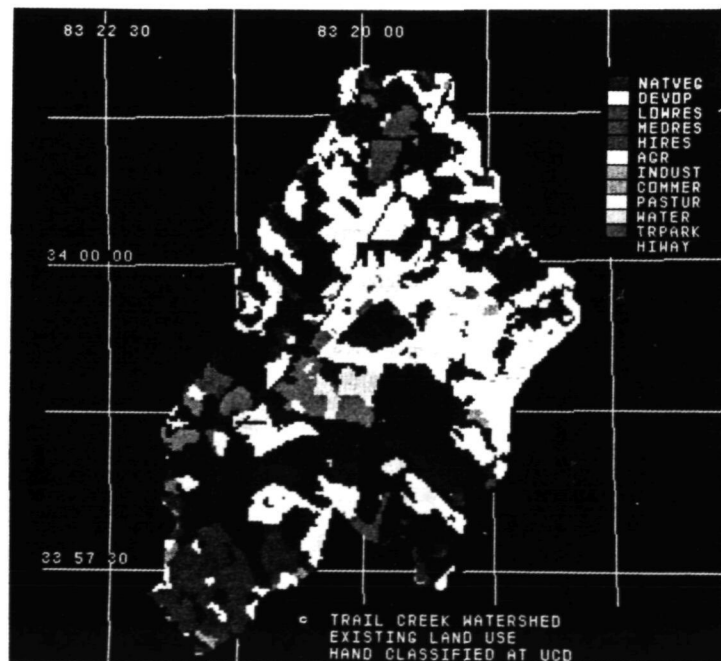


Figure 2. Trail Creek Watershed, Existing Land Use (Ground Truth)

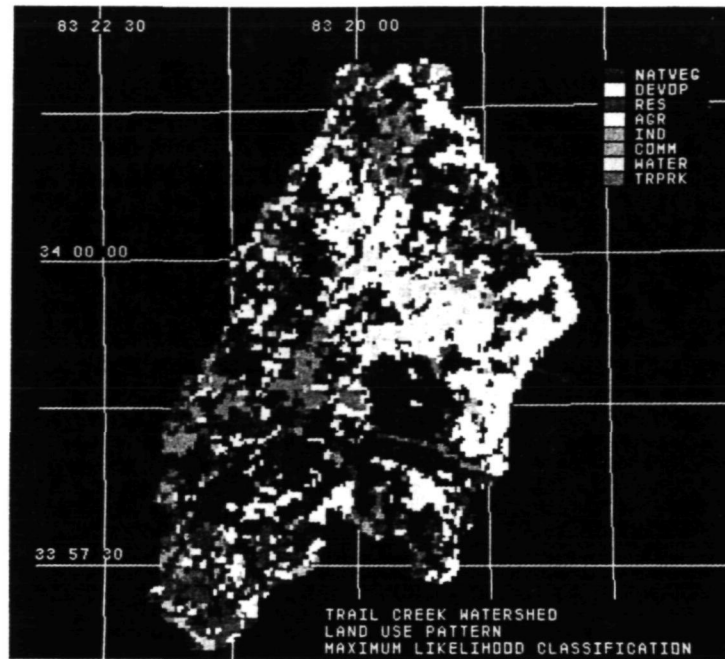


Figure 3. Trail Creek Watershed Land use Pattern, Maximum Likelihood Classifier.

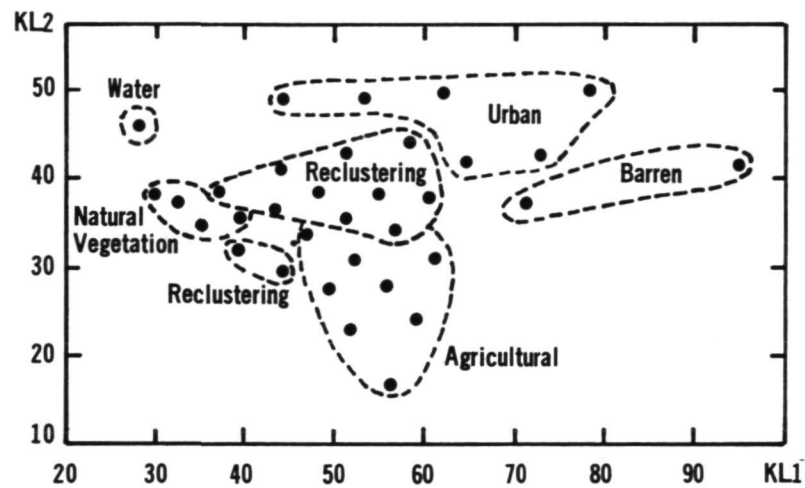


Figure 4. The Cluster Centers and the Initial Decision Made on Each Cluster.

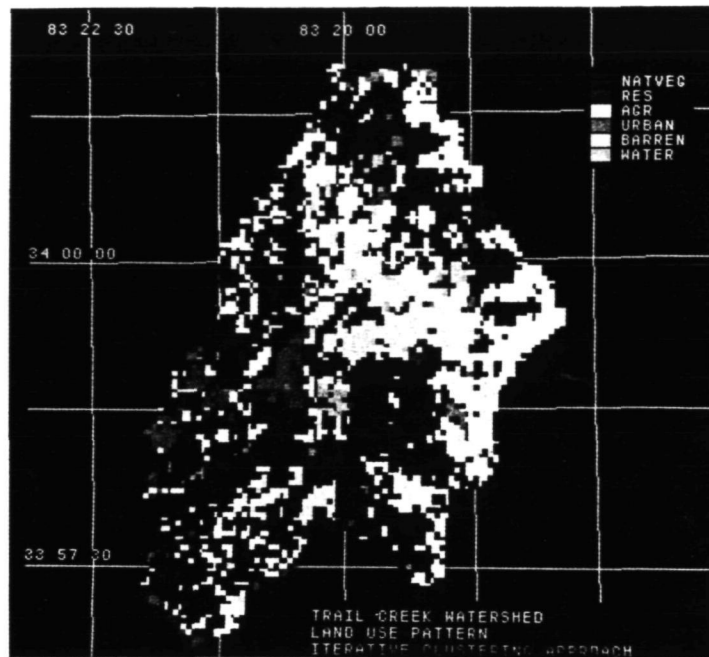


Figure 5. Trail Creek Watershed Land Use Pattern,
Operational Procedure.

9. ACKNOWLEDGMENT

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LAND UTILIZATION AND ECOLOGICAL ASPECTS IN THE SYLHET-MYMENSINGH
HAOR REGION OF BANGLADESH: AN ANALYSIS OF LANDSAT DATA

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ABSTRACT

The Haors of Sylhet-Mymensingh districts are by far the largest single inland depression in Bangladesh. The area is of significant agricultural importance and possesses unique geographic phenomena in terms of environmental and habitat supporting fisheries resources and migratory birds in the country.

The objectives of this paper are to indicate whether remote sensing data from Landsat (ERTS) imageries could be used in identifying, evaluating, and mapping landuse patterns of the Haor area in Bangladesh. In the present study one Landsat imagery of the 16 covering Bangladesh provided sufficient coverage for the Haor region of Sylhet-Mymensingh districts. Selected cloud-free imageries of the area for the period 1972-75 were studied. Imageries in bands 4, 5 and 7 were mostly used. The method of analysis involved utilization of both human and computer services of information from ground, aerial photographs taken during this period and space imageries.

The principal outcome of the Landsat data analyses on this region have been classified under the following heads in the text: general findings, technical findings, and ecological evaluation of landuse aspects.

The Haors¹ of Sylhet-Mymensingh districts are by far the largest single inland depression located in northeast Bangladesh (Fig. 1a). The area is of significant agricultural importance and possesses unique geographic conditions in terms of environment and habitat supporting fisheries resources and migratory birds in the country.

For centuries the inhabitants have been aware of the capacities and potentials of the area and the available resources. The economic activity has closely been tuned to the environmental uniqueness of the area and still there has been little change in the trends of landuse and resources exploitation. The objectives of the present investigation² have been to identify whether remote sensing data from Landsat imageries³ could be used in identifying, evaluating and mapping landuse patterns, mainly the agricultural landuse, of the Haor area in Bangladesh.

Delimitation of the area

In this study a broad Haor region has been considered in four subdivisions - two in Sylhet and two in Mymensingh districts (Fig. 1b). The actual Beels making the deepest part of the Haors are, however, located between Netrokona and Kishoreganj subdivisions in one hand, and Sunamganj and Habiganj subdivisions on the other. The Haor lies as an inverted funnel. The typical Haor area can be identified in the Landsat imageries which covers an area of 3,128 sq. miles (Fig. 2).

Importance of the Haor area to the economy of Bangladesh

Agriculture is the dominant activity of the Haor area and all other economies are oriented around it. The very topography and soil condition facilitate large scale cultivation of a number of varieties of rice. In summer, Boro paddy is grown on the rims of the Beels and numerous abandoned channels in the Haor area. Now a days, drainage has been improved in certain areas, where by early draining the areas varieties of paddy are also being cultivated. In many parts, Boro is being replaced by HYV rice. In the periphery of the Haors other crops are also grown.

During the rainy season the entire area goes under water and as soon as water recedes preparation of land for the cultivation of rice starts. In the area there are patches of rich pastures for cattle to graze. Immediately after the recession of floods, fishing activity in the area becomes prominent. The water bodies and the pastures also provide sanctuaries for flocks of migratory birds.

Apart from rice cultivation, cattle rearing and fishing are the main secondary occupations of the population in this area.

It has been estimated from the Landsat imageries that about 66 percent of the land is oriented towards Boro rice, 15 percent Aman rice and about 16 percent grazing land (including fallow). Obviously the rest covers other landuse including settlements.

The total area under rice in this area contributes to about 4.12 percent of the total for Bangladesh, producing about 3.0 percent of total Boro rice and about 2.0 percent of other rice in the country⁴.

In the past, when the population was not so dense, the yield from the land was more than sufficient to meet the demand for food. There were abundant pastures for cattle to rear. At present, because of population pressure (population per sq. mile is about 1291, and the rate of increase of population is about 3.2), the grazing lands are being increasingly converted to rice fields. The conversion is recently being facilitated by the availability of lift pumps/power pumps for irrigation and the prospects of cultivation of HYV rice in many parts.

Methodology

In the present study, one imagery of the 16 covering Bangladesh, provided sufficient coverage for the Haor areas of Sylhet and Mymensingh districts (Fig. 1b). Selected cloud-free imageries of the area for the period 1972-75 were studied. It should be noted that satisfactory cloud-free imageries are available for this part of the world (Table 1). Imageries taken in the bands 4, 5 and 7 were mostly used for the study. The method of analysis involved utilization of both human and computer services of information from ground, aerial photographs and space imageries.

Landsat imagery taken at various times clearly show current landuse practices in northeastern Bangladesh. In particular, Landsat-2 frame E-2064-03434 (27 March, 1975) was selected for digital processing. This nearly cloud-free scene was obtained near the height of the dry season and shows the extent of agricultural production associated with the Haor areas.

The initial step in the inventory process consisted of delineation of Landsat images into relatively homogeneous strata by human interpreters. For this purpose, black and white aerial photographs and topographical maps were used so as to detect major landforms - in the present case, water bodies, agricultural and non-agricultural features.

Ground truth information for two major training sites or test areas: Astagram-Bhatsala area, and Baniachang-Baruiuri area, was collected in early 1975. Subsequently other visits were made to the area. This had, however, limited practical use in correlating ground truth data with the imagery and mapping the area.

In this connection, it may be mentioned that training sites of known identity are required for computer mapping and evaluation of results. As such the training sites are selected and designed in association with aerial photographs and/or topographic maps. The task of separating or identifying pixels in Landsat-MSS data from within ground areas was found to be difficult. The problem was caused primarily by the relatively large size of the MSS-ground resolution element compared to the size of fields and other ground data. The fields in the test areas are mostly less than one acre - again they are under different landuse practices. It has been noted that a maximum of 18 pixels could fall wholly within the boundaries of a 20-acre field⁵, and such a field size is uncommon in Bangladesh.

Further, colour composite imageries (bands 4, 5 and 7 were combined with blue, green and red filters respectively) were used to further separate land-use features and geomorphic elements.

The computer compatible tapes (CCT) offer the greatest opportunity for systematic and quantitative data analyses. These CCTs can be processed using general and special-purpose computing system for the purpose of identifying the location of a variety of terrain (especially vegetative) features and for determining the total area represented by each identifiable feature.

For the present purpose, the ERIM Multivariate Interactive Digital Analysis System (MIDAS) was used. The MIDAS special-purpose computer offers an interactive, low-cost user-oriented capability for producing thematic maps derived from Landsat multispectral data. In this computer the parallel digital implementation capabilities of the processor are combined with a mini-computer to achieve near-real-time operation coupled with multiple preprocessing functions and colour displays. The data classifier is designed to perform a one pass maximum-likelihood decision with a priori probabilities, assuming multi-model Gaussian multi-variate spectral distributions.

The output of this classification process is a geometrically-rectified colour-coded hard-copy map. These maps may be produced at any convenient scales. For the present case, such maps have been prepared for Astagram-Bhatsala area (Fig. 3).

Owing to the lack of detailed ground truth, because of the problems mentioned earlier, for the area under study, an unsupervised classification procedure was selected for obtaining scene class or signatures. In this case, the Cluster programme automatically grouped Landsat data into 16 separate classes based on their spectral uniqueness in all four bands. This is further, as shown below, synthesised 6 classes to get a total or easily explicable view. These classes comprise the range of spectral variation represented in this scene. In this procedure, it is assumed that spectrally distinct scene elements represent different terrain classes and that similar elements probably contain the same or similar object⁶.

The resultant maps have been checked in the field in early 1976 and attempts have been made to establish their accuracy. The results are noted under different findings below.

General Findings

The results reported herein indicated that broad landuse pattern and geomorphic features are readily identifiable and interpretable from Landsat data. Soil types and moisture conditions can be discernable from the imageries in association with aerial photographs data or with ground truth information.

Because of very small land holding size and fragmented land utilization detail landuse pattern is difficult to delineate. In some cases, the perennial crops and aquatic covers (such as water hyacinths) overlap the rice crops and give misguided spectral information requiring degree of correction in the detail computer maps. Such an anomaly is observed in the computer map of Astagram-Bhatsala around Dhopa Beel (Fig. 4). Water bodies, nevertheless, were detectable under the best condition down to less than 5 acres in size. As such most Beels are possible to map by computer. Rural settlements, being relatively complex features mixed with orchards/perennial trees, horticulture, etc., could not be detected with confidence. Nevertheless, larger and continuous settlement units, such as Astagram and Baniachang, and a few others, such as Kishoreganj at the periphery of the Haors are identifiable (Fig. 4). Transport networks can be distinguished partially and are apparent at some time of the year in some areas, but may be very difficult to detect at other times or in other areas. Kutchra roads, road side Khals, canals, etc., which are too narrow (less than 15 feet) are difficult to detect. But such roads in association with embankments or Bandh are discernable for some areas.

Technical Findings

Broad agricultural lands (cropped and non-cropped) can be separated from other types of landuse by conventional image interpretation and image enhancement efforts with the help of colour-additives.

Generalized agricultural landuse types can be identified by spectral pattern recognition techniques with about 70 percent accuracies⁷.

Multiple imageries taken on different dates and bands can improve identification and interpretation performance significantly.

Ground truth data from training sites in the Haors were used to identify landuse pattern with some success. For some features no recognition was established but for Boro rice, fallow lands, permanent pastures, water bodies, continuous settlements and soil condition, some recognition was established.

Area measurement for large water bodies agrees with data from aerial photographs to a very high degree of accuracy.

Aquatic covers on Beels were not clearly identified in the imageries and were easily misunderstood for cropland while interpreting. But this phenomenon is possible to correct by field checking and with the help of aerial photographs.

Ecological Evaluation

Being located in the humid tropics and the area being a natural depression the Haors are covered with alluvium with lateritic intrusions or old alluvium in the periphery. Since water recedes quickly during the post-monsoon months (leaving water only in the deeper Beels), the water supplying power of the soil in winter and post-winter dry months is a critical and a crucial factor for cultivation in many parts.

The conditions which affect the water supplying power of the agricultural lands are the natural drainage and the applied irrigation. These conditions very much depend on the local climate, geology, soil profile, texture, gradient of the land and the geographical orientation.

Soil moisture affects the structural characteristics and the leaf development of the vegetation. The reflectivity of vegetation cover is known to decrease in all bands with increasing moisture content⁸. Consequently, the reflectivity of the vegetation can be used as a measure of the effectiveness of natural drainage and/or irrigation in the agricultural lands and hence the quality of the lands.

The colour composite imageries show a range of red colours corresponding to vegetation (including rice fields). A closer inspection of the areas of degrees of redness in the imageries indicate the possibility of assigning them to different moisture or land quality classes⁹. Naturally, bright red corresponds to vegetation grown in rich well moistured and deep soil, while light-red is an indicative of shallow soils with lesser moisture content. The laterite periphery, having low moisture content and higher reflectivity gives maroon to brown hue (Fig. 5). Reconnaissance aerial survey, aerial photograph interpretation and sample ground data confirm these observation. It is possible that on such information irrigation planning and eco-agricultural orientation in the Haor areas are feasible in the near future.

In this connection it should be noted that Tertiary (Mio-Pliocene) hills with troopical forest cover in further north (outside Bangladesh and overlooking the Haor areas) are represented by dark red colour in the colour composite imagery. This is obvious because of gradient affecting water table, moisture condition, vegetation cover as well as geomorphic structure facilitating runoff. Along the southern facies of the foothills, overlooking the Haors, and characterized by sudden gradient change, there are intermediate area of alluvial fans of well drained sand and sandy soil (Fig. 5). These areas are of lesser agricultural importance. They look bright on the black and white imageries, and greenish (light green where sandy soil predominates) in colour composite imagery.

Within the Haors the pinkish red and greenish patches correspond to pastures and fallow lands respectively. While deep waterbodies are shown in these imageries in black or bluish-black colour. The location are distribution of these features are of utmost importance for planning fishing industry and protecting wild migratory birds in the Haor areas.

Conclusions and recommendations

Landsat data can be used to provide useful information for a number of resources appraisal and planning, such as, agriculture, water resources, settlements and transport management, etc. This information is chiefly inferential and related to spatial reference and ground truth data. Particularly, the possible quantification of landuse data and their variations results in the applicability of these information for micro and macro planning purposes.

Repetitive Landsat coverages of a particular area are of great importance for evaluating hydrologic aspects as they affect agriculture and changes in river characteristics in a deltaic area as in Bangladesh. It is possible to estimate and forecast cultivation of different crops throughout the year provided ground information is at hand. Thus the main advantage of Landsat is its ability to record and transport large aerial data quickly and in succession and in different bands to ensure particular purpose.

Logical selection of Landsat spectral bands and processing techniques are important for effective use of derived data from the imageries. Indeed, the best utilization of Landsat data requires ground truth information as well as aerial photographs.

From the present study it has been felt that similar and other studies should be undertaken elsewhere in Bangladesh. The possible sites of such studies are the moribund delta and the coastal areas of Bangladesh. The Landsat data taken in succession of a particular area over a period may be effectively used for the study of floods, river erosion and aggradation processes in many parts of Bangladesh¹⁰. Such studies would highly be complimentary to the existing data sources in various geographic and allied fields in the country.

NOTES

1. Haors are the annually flooded depressed areas with deeper and permanently innundated parts called Beels. The area can readily be delineated from Landsat imageries of any band taken in any time of the year.
2. This paper is a part of the Sylhet-Mymensingh Haor Project undertaken by the Department of Geography, Jahangirnagar University, Dacca (Bangladesh) in collaboration with the Environmental Research Institute of Michigan (ERIM), USA in 1975. The overall project, sponsored by a grant from the USAID, is designed to demonstrate the application of Landsat data to agricultural planning and regional development in Bangladesh.
3. Synchronized with the sun, an earth satellite called Landsat swings in a near-polar (99.1°) orbit in an 18-day cycle about 560 miles above the earth. At the equator each pass is some 1,800 miles west of the previous one and every 25 seconds it scans an area of about 1,300 sq. miles. The Landsat-I (earlier termed ERTS-I) launched on July 23, 1972, is still gathering earth resources data. It was joined on January 22, 1975, by Landsat-II. The Landsat does not use photographic cameras but an ingenious instrument called a Multispectral Scanner or MSS, which uses an oscillating mirror that scans the earth and a telescope that focuses visible and near infra-red light waves reflected from the earth into the satellite's radiation detectors, which measures the light intensities of 1.1-acre picture elements or pixels in four different bands. These values are converted into computer digested numbers and transmitted back to earth at the rate of 15 million units per second. Through an electron-beam recorder, this stream of data becomes imagery on photographic film ready for various uses.
4. Govt. of Bangladesh, Bureau of Statistics (agriculture section), Unpublished data on Mymensingh and Sylhet districts, 1975; and Govt. of Bangladesh, Ministry of Agriculture, Bangladesh Agriculture in Statistics, Nr. 1, 1973, Dacca, 1974.
5. A maximum of 18 pixels could fall wholly within the boundaries of a 20-acre field (see: Myers, W.L., Malila, W.A., Sarno, J.E., Wagner, T.W and Lewis, J.T., The use of ERTS data for a multidisciplinary analysis of Michigan resources. Michigan State University - Agricultural Experiment Station. ERIM, 1974, p. 19).
6. The authors thank Mr. T.W. Wagner, A.R.G. of the ERIM, USA, for kindly supplying the computer processed maps for the Haor Project which have been used in this paper.
7. This is as good performance as has been achieved with aircraft data (note: Erb, R.B., The utilization of ERTS-I data for application in agriculture and forestry. Third ERTS-I Symposium, Vol. 1(A), Washington, D.C., Dec. 10-14, 1973, Pp. 75-81).
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9. Oime, A.R., Bowden, L.W., and Minnigh, R.A., Remote sensing of disturbed insular vegetation from colour infra-red imagery. International Symposium on Remote Sensing of Environment, Vol. 2(7), 1971, P. 1235; and also Mayers, V.I., op. cit.
10. Chowdhury, M.I., and Elahi, K.M., Aspects of land utilization in the Sylhet-Mymensingh Haor areas of Bangladesh: an analysis of Landsat data. Second Annual Conference of the Bangladesh Association for the Advancement of Science, January 23 to 26, 1977, Bangladesh Agricultural University, Mymensingh.

TABLE I. LANDSAT-I (ERTS) Imagery: Percentage of Frames with below 30 per cent Cloud, 1972-73.

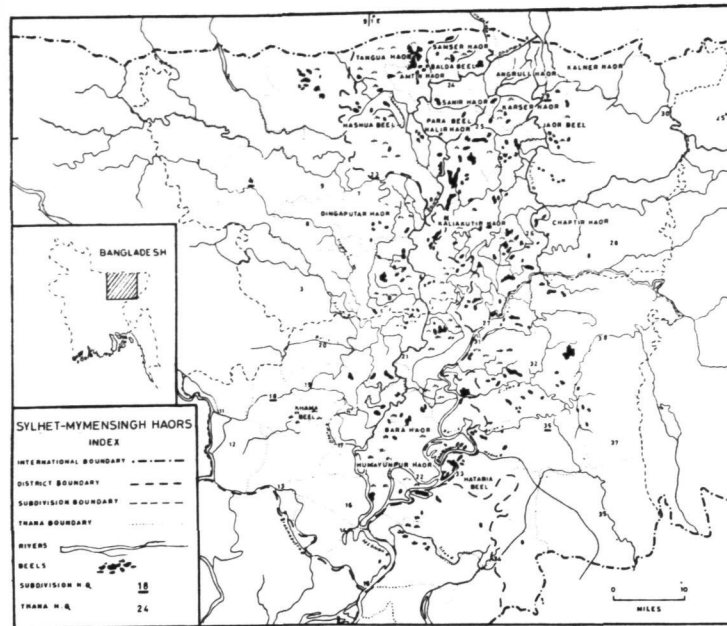
<u>Area</u>	<u>Per cent of frames for spatial studies</u>	<u>Per cent of frames for time dependent studies</u>
Latin America	50	38
Africa	85	63
South Asia	93	88

Source: Howard, J.A., Concepts of integrated satellite surveys, Third ERTS-I Symposium, Vol. 1(A), Washington, D.C. Dec. 10-14, 1973, Pp. 523-537.

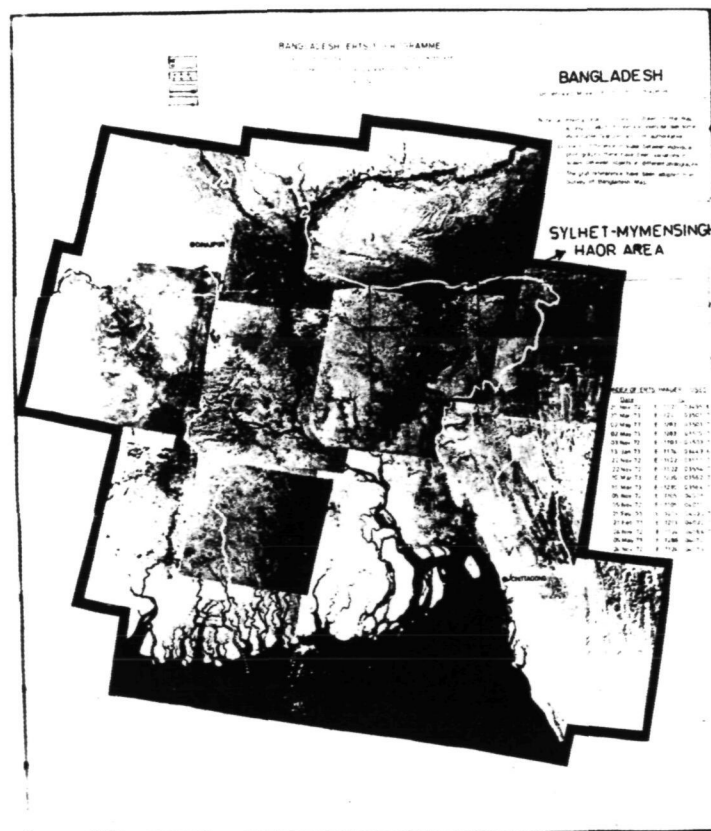
FIGURE 1. Location map of the Sylhet-Mymensingh Haor Area, Bangladesh.

INDEX OF PLACE NAMES

1. Durgapur
2. Purbadhala
3. Kendua
4. Netrakona
5. Madan
6. Kaliajhuri
7. Mohanganj
8. Atpara
9. Barhatta
10. Kalma Kanda
11. Hussainpur
12. Pakundia
13. Katiadi
14. Kuliarchar
15. Bhairab
16. Bazitpur
17. Nikli
18. Kishoreganj
19. Karimganj
20. Tarail
21. Itna
22. Aushtagram
23. Dharmapasha
24. Tahirpur
25. Jamalganj
26. Dera
27. Sulla
28. Jagannathpur
29. Sunamganj
30. Chhatak
31. Azmiriganj
32. Baniachang
33. Lakhai
34. Madhabpur
35. Chunarughat
36. Habiganj
37. Bahubal
38. Nabigani



1a



1b

FIGURE 2. LANDSAT Imagery of Northeast Bangladesh.

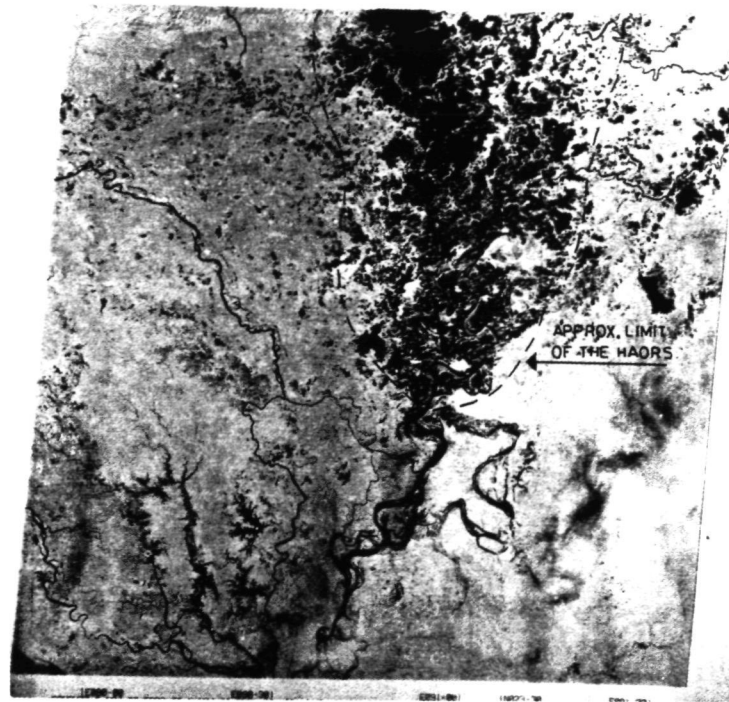


FIGURE 3. Computer maps of Astagram-Bhatsala area in relation to Northeast Bangladesh.



a) Meghna depression: Northeast Bangladesh.

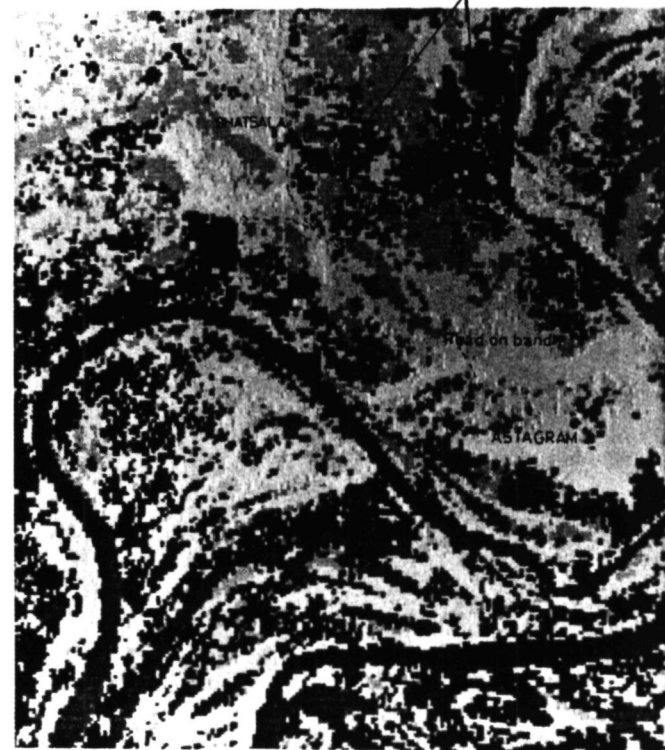
Grazingland / current fallow



AUSHTAGRAM AREA (64 km²)
 Northeastern Bangladesh
 27 MAR 75
 Landsat Frame 2064-03434
 16 Classes

ΣERIM

Irrigated cropland



AUSHTAGRAM AREA (64 km²)
 Northeastern Bangladesh 27 MAR 75
 Landsat Frame 2064-03434
 6 Classes

ΣERIM

b) Astagram-Bhatshala area.

FIGURE 4. Sections from Aerial photographs and Topo-sheet showing Astagram-Bhatsala area (referred in relation to Figs. 2 and 3).

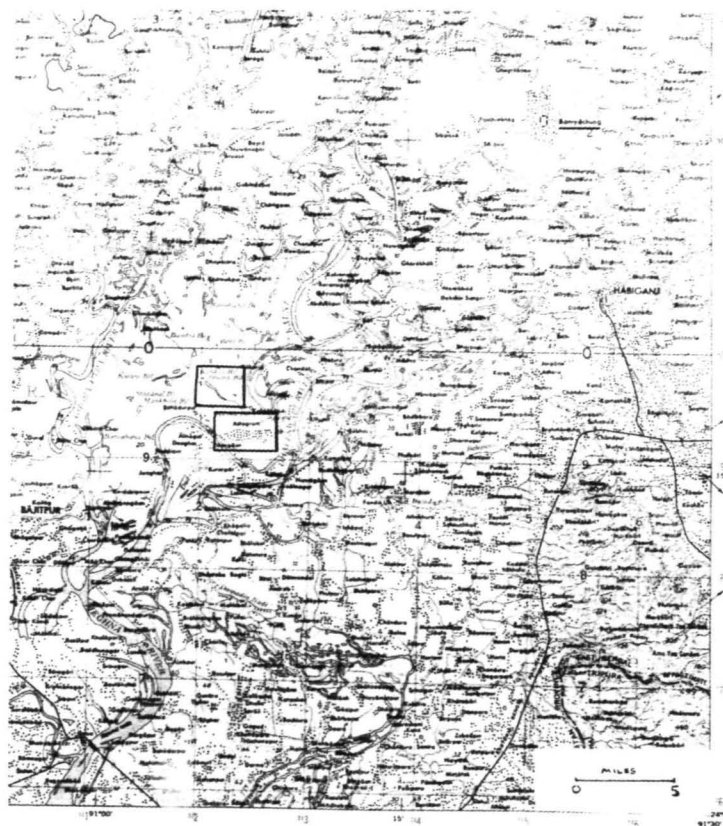
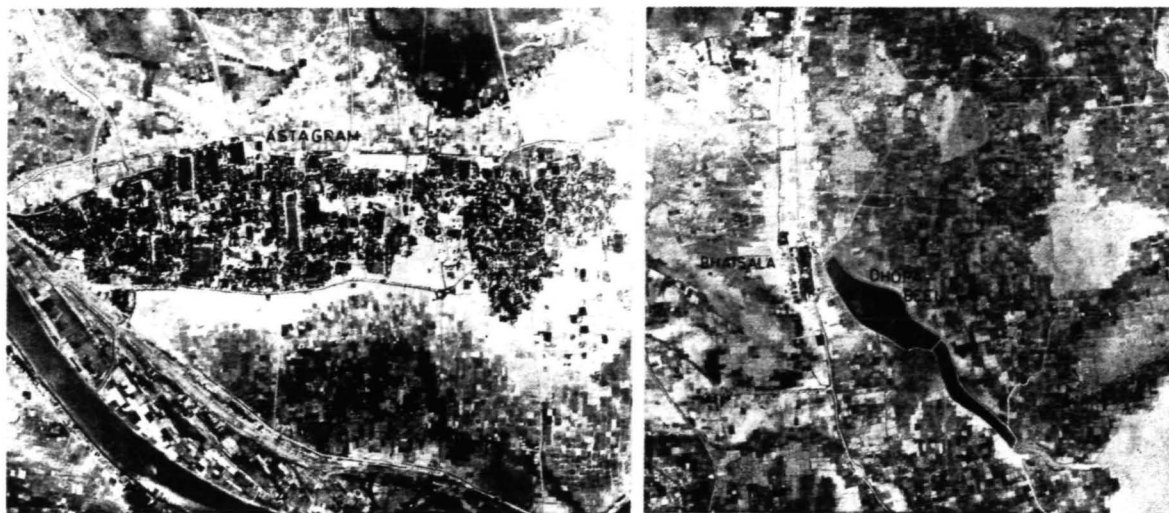
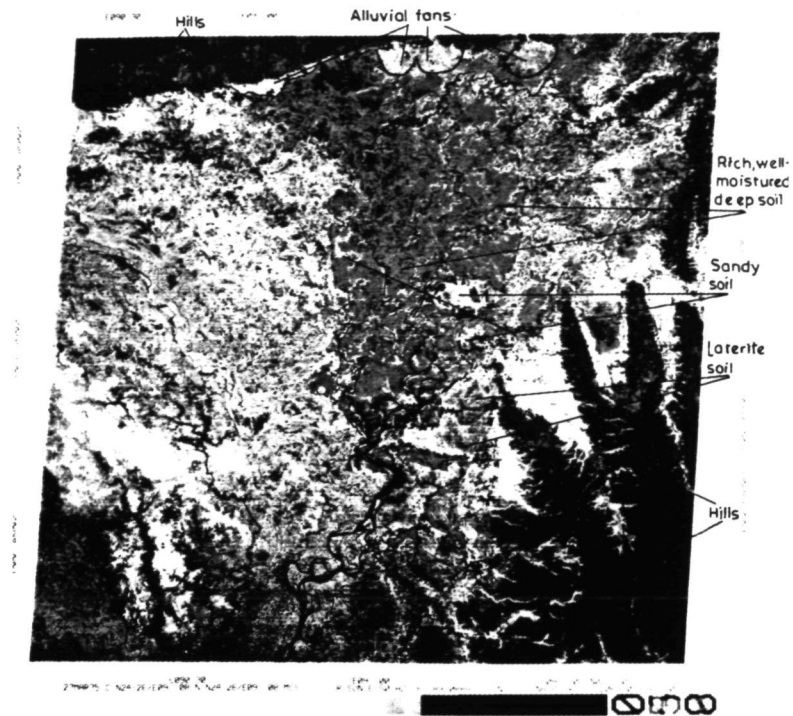


FIGURE 5. Colour Composit Imagery of Northeast Bangladesh.



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OF POOR QUALITY

USE OF AERIAL THERMOGRAPHY
IN CANADIAN ENERGY CONSERVATION PROGRAMS

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ABSTRACT

This paper summarizes recent developments in the use of aerial thermography in energy conservation programs within Canada. Following a brief review of studies conducted during the last three years, methodologies of data acquisition, processing, analysis and interpretation are discussed. Examples of results from an industrial-oriented project are presented and recommendations for future basic work are outlined.

1. INTRODUCTION

With growing complexity of the industrial economy and the modern trends towards compulsive consumption, the demand for energy in Canada has been accelerating. For example, during the 1961-1971 period, energy consumed by the average Canadian increased by about 50% (1). Until recently, energy policy in Canada was limited to measures directed at locating, acquiring and delivering enough energy to meet the expanding demands. It has become evident, however, that this high energy consumption rate cannot be sustained indefinitely and energy conservation programs must be implemented.

During the past three years numerous energy conservation programs have been initiated by various federal and provincial government departments, universities, school boards, businesses and institutions. In the same period attempts have been made to evaluate the usefulness of aerial thermography for detecting excessive heat loss from buildings and heating lines, and to determine its role in identifying the causes of excessive heat loss and in developing plans for remedial measures.

2. OVERVIEW OF CANADIAN PROJECTS

The Canada Centre for Remote Sensing (CCRS) has been collecting airborne thermal infrared and supporting photographic data for heat loss detection during the last three years (see Table 1). Initial studies were of an exploratory and qualitative nature, with emphasis on detection of major problem areas. The technique proved successful for locating damaged flat roofs, defective heating lines, water

leaks around exhaust vents, and unnecessary energy consumption in locations such as heated ramps or sidewalks which were left operating after snow had melted from the surface (2,3).

Exploratory work aimed at quantitative assessment of heat loss from residential structures revealed the importance of considering in detail the parameters affecting the heat transfer from the interior of the house to the roof surface. Since the attic space forms a buffer between the ceiling insulation and roof surface of a house, it is necessary to analyse the heat transfer and heat loss mechanisms by taking into account all means of heat dissipation including attic ventilation, conduction-convection from the roof surface, and radiation from this surface (4). CCRS is presently conducting a joint experiment with an electric utility company to evaluate the use of aerial thermography for a quantitative estimation of heat losses from a wide spectrum of residential structures. A test area covering approximately two square kilometers was chosen in Ottawa. This area contains homes built between the end of World War II and the present and includes single family, semi-detached, and condominium structures with various types of heating systems. Aerial thermograms have been collected over this area on several dates and times of day during the 1976/77 heating season, and questionnaires have been sent to approximately 2000 homes in the area to obtain information on house insulation, attic ventilation and roof characteristics. In addition, a mathematical model relating roof surface temperature to ceiling insulation has been developed (4). Attic temperatures and humidity were measured in three test homes in order to assess the validity of some of the model assumptions and aid in developing the model. The aerial thermograms are presently being analyzed and results should be available in the near future.

To take full advantage of the aerial thermography technique, the Ontario Centre for Remote Sensing (OCRS), Ontario Ministry of Natural Resources has been conducting, since early 1975, a progressive aerial thermography program with the aim of developing an operational methodology for employing this technique on a large scale. Initially, selected test sites with single family dwellings, commercial, public and apartment buildings were chosen for study. Using the Daedalus thermal scanning system and criteria specified by OCRS, thermal imagery was obtained and processed by the Airborne Operations Section of CCRS. Data were acquired from altitudes of 360 m, 480 m and 600 m above ground level and under various atmospheric conditions. From this initial test series, 480 m was chosen as the optimum altitude on the basis of the spatial and thermal resolution elements of acquired data and the quality and size of photographic enlargement that can be produced from such imagery.

The findings of the OCRS initial test flights, presented in several in-house reports to the Ontario Ministry of Energy, have lead to a much expanded program in the residential communities of Ontario. The first large scale community-oriented thermography presentation in Canada will take place during May 1977. Thermal imagery of the town of Lindsay, Ontario (population 12,872) will be made available to the citizens as part of a major energy conservation awareness program. An interpretation centre will be established where each house owner will be able to view the thermograph of his house and be provided with its interpretation. This project has been a joint venture by OCRS and the Ontario Ministry of Energy.

Another energy conservation program initiated and funded by the Office of Energy Conservation (OEC) of the federal Department of Energy, Mines and Resources covers two Maritime provinces and makes extensive use of aerial thermography. The program, which is presently coordinated by a joint federal-provincial committee, consists of several related elements aimed at encouraging greater energy conservation. These elements are: energy use statistics, mobile energy audit buses, design of corrective measures, technical education workshops, in-plant promotion, grants for capital projects, and aerial thermography. These elements are intended to contribute to the effectiveness of the various decision making and action steps involved in improving energy efficiency of an industrial establishment. Aerial thermograms will be used for general presentation in workshops, seminars, displays, etc. They will also be used in the bus program, where an aerial thermogram of an industrial site will be presented to industry management during a visit by a mobile energy audit bus. Thermogram anomalies attributed to excessive heat loss will be discussed, and used to both increase the manager's awareness of and participa-

tion in the program and as an aid in the design of corrective measures. During March 1977 aerial thermograms over most of the industrial and institutional sites in Nova Scotia and Prince Edward Island were collected. Several establishments have been analyzed in a pilot project (5) and some of the results are presented in Section 4.

3. METHODOLOGY

3.1 Data Acquisition and Processing

Remote sensing data have been collected by CCRS aircraft and sensors for Canadian aerial thermography experiments. The sensors may be carried by either of two DC-3's, a Falcon Fan Jet, or (in the future) a Convair 580. In a typical mission, two flights are undertaken within a 24 hour period. Normal colour or colour infrared aerial photographs (or both) with a 60% overlap and 30% sidelap and thermal infrared scanner data are acquired during the near-noon, daytime flight, and thermal scanner data only are acquired at night. Single channel (8-14 μ m) or dual channel (3-5 μ m, 8-14 μ m) data may be collected. The night flights are usually at least 4 hours after sunset at an altitude of 360 to 490 m above ground level under the following meteorological conditions: night temperature below 0°C, clear skies or minimal cloud cover and light winds. These specifications are considered only tentative, however, and further work aimed at determining the optimum data acquisition conditions is underway.

Aerial photographs are developed and reproduced at the National Air Photo Library in Ottawa. Thermal scanner data are reproduced as a 12.5 cm wide black and white (B&W) transparent image in two modes: analogue and level-sliced. Two level-sliced sets are commonly used. The first, usually referred to as the "master set", is obtained by dividing the temperature range between two reference levels into six equal intervals and displaying data within each interval as a single gray tone. The reference levels are obtained within the infrared line scanner by repeated viewing of two internal constant temperature plates. The second set, or "subset", repeats the above quantization procedure but the reference levels are now chosen as any two of the levels within the master set. Typically, a range encompassing two to three slices of the master set contains most of the information and hence is subdivided into six equal intervals. The analogue data may also be digitized to 256 levels (8-bits) for recording on computer compatible tapes for quantitative analysis or for display as a 12 interval, level sliced, colour coded image on a 23 cm wide paper print strip.

3.2 Interpretation

3.2.1 Visual Analysis

The primary source of remote sensing data for heat loss analysis is the nighttime thermogram. Typically, all three image forms (analogue, level sliced master set, level sliced subset) are utilized. For a given site, the thermograms are magnified as required and reproduced as positive B & W prints, which have been found preferable to transparencies (5). Prints are easy to handle in the office and on site, and are convenient for interpretation (marking, referring back and forth between various sources of information, roof delineation, etc.) Stereoscopic aerial photographs provide valuable reference data. In most projects, both colour and colour infrared positive transparencies have been produced at a scale of approximately 1:2,800 to allow detailed examination of the roofs. In a recent project, 70 mm colour and colour infrared stereoscopic photographs (scale 1:12,000) were produced instead, thus decreasing the total data acquisition costs by almost 50%. These proved satisfactory for an analysis of industrial buildings (5). Meteorological data, on-site observations, and other auxiliary data may be used to aid in the interpretation of anomalies observed on the various thermograms. Examination of aerial photographs indicates which of the anomalous warm areas are related to smoke stacks, skylights, sides of buildings, roof vents or penthouses. The roof features can create 'natural' warm points, although care must be taken to analyze their thermal shape and size. Damaged flashings around vents and penthouses are well known water entry points; if the thermal expression around such feature is excessively large or oddly shaped, then the site should be classed as a potential problem area. The remaining apparent heat anomalies are analyzed to determine whether they could

be accounted for by differences in surface materials, presence of water, reflection from the surroundings, roof geometry, etc. Areas where excessive or unexpected heat loss is suspected are marked on the thermogram prints and assessed during an on-site visit where appropriate. These areas often experienced insulation damage through moisture, compaction or other means, thus resulting in reduced thermal resistance and higher heat loss.

A non-destructive method for measuring moisture in roof insulation involves bombardment of a test area with neutrons and measurement of the thermal recoil of the neutrons caused by the presence of water. This radioisotopic method of moisture detection has demonstrated excellent correlation between high moisture content in the roof insulation and areas of high thermal radiance in the thermograms (3).

3. 2. 2 Digital Analysis

Digital processing of airborne thermal infrared imagery is a powerful technique for quantitative image analysis. CCRS has two image processing systems. The CCRS Image Analysis System (CIAS) is based upon a PDP-11/70 computer and an IMAGE 100 and is capable of performing various overlay, transformation, classification, display, and output operations. The Modular Interactive Classification Analyzer (MICA) uses a Bendix Multispectral Analyzer Display connected on-line to a large time-sharing computer. Its capabilities are similar to CIAS but all algorithms are implemented by software. Consequently, MICA is an ideal system for methodology development and will be used extensively in the CCRS project on residential heat loss. Specialized software is available to display a digitized thermogram as an image on the TV display. A cursor-selected area of the imagery may be transferred to a disk file and converted to apparent blackbody temperatures. These temperatures can be related to roof surface temperature and then to heat loss. Changes in models, data calibrations and specific house parameters such as house style, roof pitch, and type of roof material may be accommodated relatively easily.

4. ILLUSTRATIVE RESULTS

Selected examples of aerial thermograms presented in this section were analyzed under contract by Philip A. Lapp Ltd. with OCRS involvement in a pilot project conducted by CCRS and OEC in the province of Prince Edward Island. Data were acquired on March 2, 1977 between 2100 and 2200 hrs. Atlantic Standard Time. Air temperatures were below 0°C all day and -5°C at night. The wind was 8 to 16 km/hr and skies were clear with few scattered clouds. Although the majority of the roof were clear and dry, some snow and standing water were evident on the aerial photographs taken at approximately noon on March 4. Ground information was obtained during visits to the sites on March 17 and 18 after the thermograms had been examined. The site visits helped to validate the initial interpretation of many observed anomalies on the thermograms.

Figure 1 shows a visual photograph and a nighttime thermogram of a shopping centre. In the thermogram light tones correspond to high radiation levels, and thus indicate "warm" sites. The shopping centre building was conspicuously light on the thermogram relative to other similar structures. Aerial photographs, daytime thermograms, and site inspection indicated that the roof was ice-covered to various degrees with (A, Figure 1b) or without (C) liquid water under the ice. In the high radiance areas the roof surface was soft, suggesting breakdown of the waterproof membrane. The "cold" areas (B, Figure 1b) were found during the inspection to be ice-free with a firm dry membrane. Thus the presence of ice appeared to correspond to areas of weak membrane and consequently of water-damaged insulation leading to a higher heat loss. Intermediate radiance levels on both daytime and nighttime thermograms exhibited at C (Figure 1b) could be explained by thinner ice cover and properly functioning thermal insulation (relative to A). The poor thermal performance of this roof was indicated during the discussion with building managers.

Thermal image of a building with different roofing materials is shown in Figure 2. Part A (Figure 2b) is covered with 1.8 cm thick rigid insulation under a tar/pitch membrane without gravel. The remainder of the building has 1.8 cm rigid insulation covered with tar and gravel. In general, the tar-only area appears "colder" than the tar and gravel section. This difference could be caused by different radiative physical properties (emissivity) of the surface materials. However, other explanations are possible. Part A is 3m higher than the remainder of the roof and could thus experience higher sensible heat loss. Furthermore, a small portion of the tar and gravel roof (B, Figure 2b) exhibited radiation levels similar to those of part A. The tar and gravel roof also contains eight skylights (C, Figure 2b), smokestacks (D) and a penthouse (E). These features and the surface discontinuities can be expected to affect the thermogram. The above examples show that a careful thermogram analysis is necessary to avoid interpreting emissivity and geometry effects as heat loss anomalies. The thermogram does, however, contain a significant thermal anomaly (F, Figure 2b). Aerial photography and on-site examination established this to be water collected at a low spot on the roof. Continued presence of water for extended periods of time is known to eventually cause roof deterioration.

Figure 3 is a thermogram of a hospital whose roof consists of three sections. In the upper section (A, Figure 3b), no heat anomalies unrelated to vents or similar structures could be identified. This roof is of the inverted type, i.e. a waterproof membrane is covered with slabs of waterproof insulation and these are in turn overlaid with 5 to 10 cm of crushed rock. This design presents problems in detecting a damaged membrane even when the roof is thermally sound. The central portion (B, Figure 3b) was uninsulated, and this is evident from a higher radiation level of this section. In the lower section (C), the roof was of conventional construction. The "warm" anomaly in this section was identified as a low spot near a drain located in the vicinity of a penthouse and interpreted as an incipient roof failure around the drain; otherwise, the roof had a uniform appearance on both air photographs and thermograms.

5. SUMMARY AND CONCLUSIONS

Results of Canadian studies employing aerial thermography for heat loss detection have demonstrated the usefulness of this technique in locating anomalies associated with excessive heat loss. The value of aerial thermograms for increasing the interest, participation, and motivation of building operators has also been indicated (5), and should become of major significance in future energy conservation programs.

The quantitative aspects of heat loss from roofs are not well understood at the present time. Some of the on-going work should yield a better understanding of the extent to which roof surface temperature is a measure of ceiling insulation and of total heat loss. Additional studies are required to determine the effect of snow, ice, water, temporal changes during the night such as cooling rates, and emissivity on the relationship between roof surface temperature and heat loss. Understanding these parameters is important because optimum conditions are rarely present in large scale projects.

The future of aerial thermography in energy conservation appears very promising. However, it is very important to maintain credibility of the technique by not extending it beyond its limits. These limits depend upon the general understanding of the methodology as well as on specific conditions at individual sites.

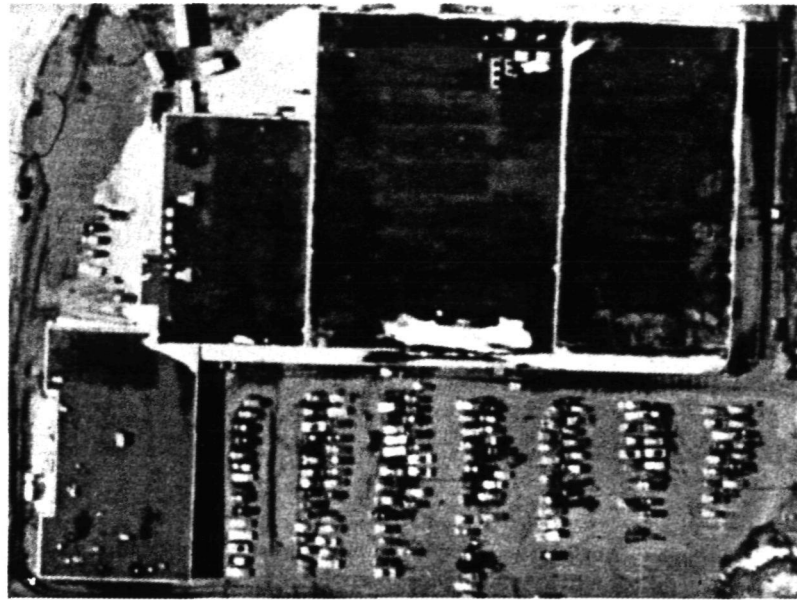
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2. Goldins, J. , Ministry of Transport, Ottawa, Ontario, 1977, private communication.
3. Lawrence, G. R. , "Airborne Thermal Sensing Program for the Detection of Building Heat Loss", Canadian Symposium on Thermography and Energy Conservation, Toronto, Ontario - Montreal, Quebec, Canada, December 1976.
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5. "The Assessment of Heat Loss from Buildings by Means of Aerial Thermography - a Pilot Project Conducted for the Canada Centre for Remote Sensing, Department of Energy, Mines and Resources", Philip A. Lapp Ltd. , Toronto, Ontario, March 1977.

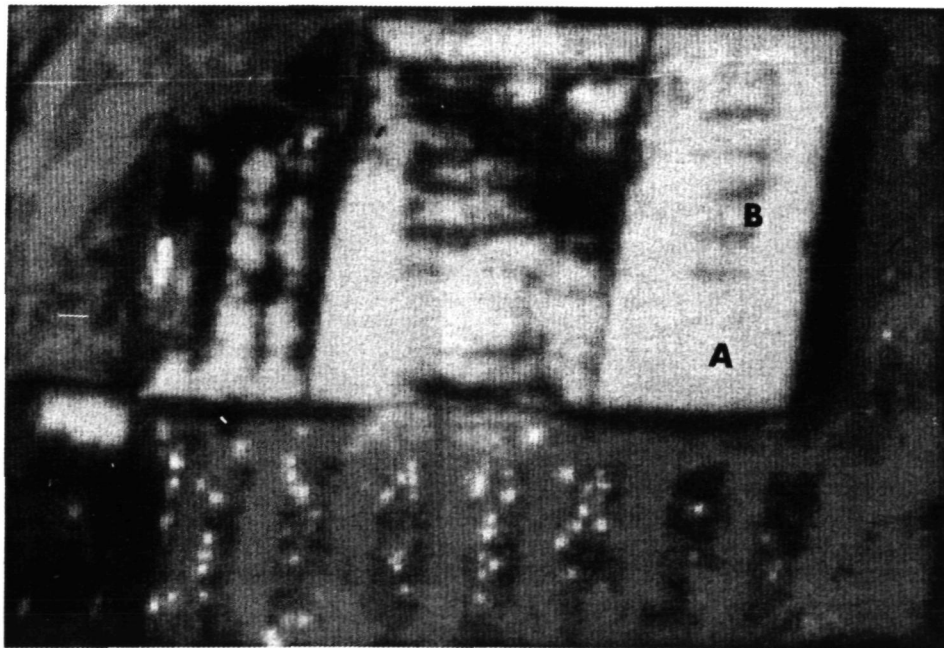
TABLE 1 Summary of Aerial Thermography Projects
for Heat Loss Detection in Canada

AGENCY	YEAR	LOCATION	STATED OBJECTIVE
Canadian Penitentiary Service	1975	Cowansville, Quebec	To locate underground leaks in heat distribution lines.
	1975	Drumheller, Alberta	
Philips Cable Ltd.	1974	Brockville, Ontario	To determine the extent of heat loss from buildings and heat distribution lines.
Ontario Centre for Remote Sensing	1975	Toronto, Ontario	To detect energy loss in buildings
	1976	Toronto, King City, Ontario	
	1977	Toronto International Airport, Cobourg, Centralia, Ontario.	To determine locations of excess heat loss from industrial sites.
Ontario Centre for Remote Sensing (Ontario Ministry of Energy)	1976	Stratford, Brockville, Sudbury, Lindsay, Ontario	A preliminary study on heat loss from residential buildings and presentation to community in an energy conservation program.
	1977	Perth, Prescott, Arnprior, Guelph, Sault St. Marie, Ontario	
Canadian Department of Transport	1976	Ottawa, Ontario	To evaluate the use of aerial thermography to detect roof deterioration at Canadian airports.
Canada Centre for Remote Sensing Canada Dept. of Energy, Mines and Resources	1977	Ottawa, Ontario	To evaluate the use of aerial thermography to quantitatively estimate heat losses from residential structures.
Ottawa Hydro	1977	Ottawa, Ontario	To evaluate the use of aerial thermography to quantitatively estimate heat losses from residential structures.
Office of Energy Conservation, Canadian Dept. of Energy Mines and Resources	1977	All industrial, commercial and institutional sites, in P. E. I. and N. S.	To provide heat loss information for Maritime industrial sites, schools, hospitals etc. in conjunction with the comprehensive national energy conservation program.
Canadian Dept. of Public Works	1977	Selected federal buildings in Ottawa, Ontario	To detect heat losses and damaged roofs from federal

AGENCY	YEAR	LOCATION	STATED OBJECTIVE
McMaster University	1975	Hamilton, Ontario	To detect heat losses from buildings and heat distribution lines.
York University	1975	Toronto, Ontario	
University of Guelph	1975	Guelph, Ontario	
University of Waterloo	1974	Waterloo, Ontario	
University of Calgary	1976	Calgary, Alberta	

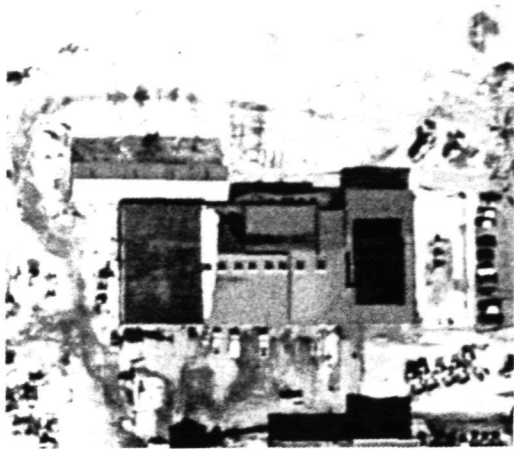


(a)

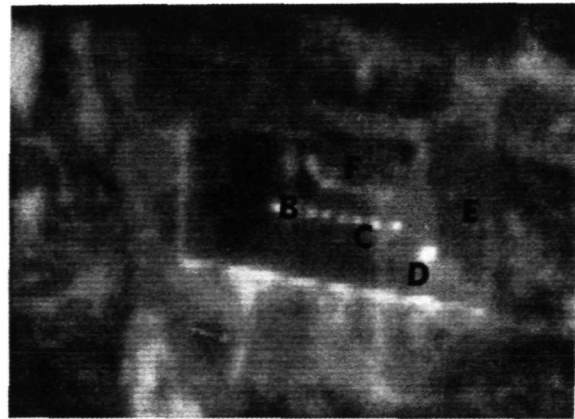


(b)

Figure 1 Aerial photograph (a) and nighttime thermogram (b)
of a shopping mall. See text for explanation

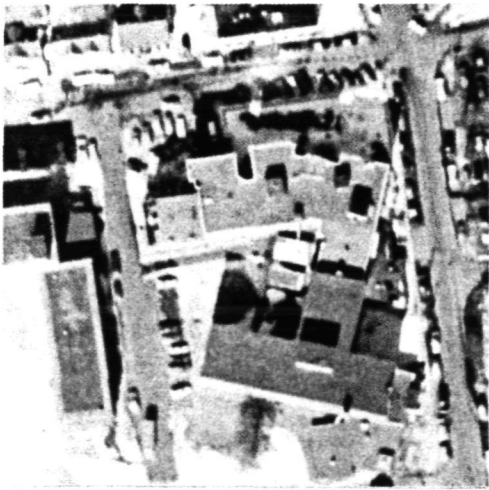


(a)



(b)

Figure 2 Aerial photograph (a) and nighttime thermogram (b) of a heavy machinery depot . See text for explanation



(a)



(b)

Figure 3 Aerial photograph (a) and nighttime thermogram (b) of a hospital. See text for explanation

CAPABILITIES OF OPERATIONAL
INFRARED SOUNDING SYSTEMS FROM SATELLITE ALTITUDE

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ABSTRACT

Operational soundings have been produced from Vertical Temperature Profile Radiometers (VTPR) since October 1972. In September 1973, a description of the processing system (McMillin et al.) was published. Changes to the processing system are described. A new series of operational sounding instruments is being built for launch in 1978. Capabilities of this system are compared to the present VTPR. In the past, radiances have been used to duplicate radiosonde information. Approaches not based on producing radiosonde profiles are being incorporated into operational procedures.

1. INTRODUCTION

Given a temperature profile and cloud distribution, it is relatively easy to integrate the radiative transfer equation to obtain radiances. However, to obtain profiles of temperature and humidity from radiance measurements, the more difficult inverse problem must be solved. There are two main problem areas: the retrieval of temperature profiles from clear radiances and the derivation or selection of clear radiances from measurements which are contaminated by clouds.

The retrieval of temperature is based on radiometric measurements at several wavelengths in an absorbing region for a gas with a uniform mixing ratio in the atmosphere. Radiation at each wavelength is characteristic of an average temperature over a relatively thick layer of the atmosphere. Two basic approaches to the problem have been tried. Presently, approaches which rely on the physics of the problem are limited in accuracy by uncertainties in the knowledge of atmospheric transmittance parameters upon which the approaches depend. However, these approaches offer the hope of greater accuracy in addition to being capable of producing soundings from a stand-alone system that does not rely on measurements from other instruments such as radiosondes. Ongoing studies are directed toward better laboratory measurements of the spectroscopic parameters to improve the models used to calculate atmospheric transmittance. While physical models are being improved, current systems use statistical information in the form of regression of radiosonde temperature profiles as a function of satellite measurements that are reasonably simultaneous in time and coincident in space.

In the past, most of the sounding effort has been directed toward the retrieval problem. Recent papers by Fleming (1977) and Rodgers (1976) describe the relationships between the numerous and seemingly diverse solutions which have appeared. However, the errors in clear radiances are the major limiting factor in achieving better accuracy. Early approaches concentrated on finding holes or areas that were completely cloud free. There was a problem of some residual cloudiness contaminating the measurements, but the major limitation of the method was a lack of soundings in the meteorological interesting areas. Current methods are based on the adjacent field-of-view approach originally proposed by Smith in Fritz et al. 1972 and Smith et al. 1970. This method is

based on the assumption that clouds in adjacent spots are at the same level, a condition that does not hold over significant areas of the globe. Most procedures which use this method employ a screen to reject questionable values. Although this method is not limited to cloud-free spots, it is limited to areas that are partly clear and have a uniform cloud height. While more soundings are produced with this system, it still fails to produce soundings in many areas of meteorological interest.

2. THE PRESENT METHOD

Production of operational temperature soundings from satellites began shortly after the launch of the first pair of Vertical Temperature Profile Radiometers (VTPR's) on NOAA 2 in October 1972. To provide continuous coverage as various satellite components failed due to aging, NOAA 2 was followed by NOAA 3, NOAA 4, and NOAA 5. Each of these satellites carried two instruments for redundancy. Table 1 shows the periods that various satellites were used. After an initial failure, one of the instruments on NOAA 2 recovered and was used until it failed a second time in October 1974.

On April 5, 1974, NOAA 3 was rotated in orbit so that space was viewed through the normal earth position. This exercise revealed a scan-position dependent bias in the data as well as a difference between earth and space ports. Both were caused by stray radiation from parts of the instrument reaching the detector. Baffles were added to later instruments carried on NOAA 4 and NOAA 5 to correct the problem.

The initial VTPR processing system has been described in McMillin et al. 1973. Since 1973, several of the procedures used to calibrate the data, eliminate cloud effects, and produce temperature retrievals have changed. Changes to the calibration algorithm have been minor. Instruments on NOAA 5 and later satellites measure the patch temperature every scan instead of the secondary optics temperature.

Both the clear radiance procedure and retrieval algorithm have changed extensively from methods described in McMillin et al. The clear radiance procedure is still based on the assumption that if cloud amount is the only parameter that changes between two adjacent fields-of-view, then radiances for any channel are a linear function of cloud amount. If a clear radiance value is known for any channel, then the cloud amount can be determined and clear radiances for other channels can be derived from the linear relationship between radiance and cloud amount as suggested by Smith. In the VTPR system, window radiances for two spots are compared to determine if values differ enough ($>1 \text{ mW/cm}^2\text{sr cm}^{-1}$) to define a line and an estimated clear value for the window channel is calculated from a sea surface temperature analysis and the NMC forecast air temperatures. Then the ratio of the radiance difference between the two measured values to the difference between one of the values and the calculated clear value is obtained from

$$r = \frac{I_1(v_i) - I_2(v_i)}{I_{\text{clr}}(v_i) - I_1(v_i)} \quad (1)$$

where r is the ratio,

$I_1(v_i)$ is the radiance at wavenumber v_i for spot 1,

$I_2(v_i)$ is the radiance at wavenumber v_i for spot 2, and

$I_{\text{clr}}(v_i)$ is the calculated clear radiance at wavenumber v_i .

Knowing r , values of $I_{\text{clr}}(v_i)$ are obtained for the remaining channels.

In early versions of the processing system, the resulting clear radiance estimates were combined in a histogram and a single value was obtained. That has been changed to an approach based on screening the values to provide a distribution that is symmetric, and then averaging the result. Three separate

tests are involved. Each VTPR scan spot not on the edge of a scan is surrounded by eight scan spots which touch it on a corner or a side. For a given spot, pairs are formed with four of the adjacent spots; the remaining four pairs will result with one of the adjacent points as the center. Each of these four pairs has one point, the center point, in common. In the first test, derived radiances for each of the 49 groups of four pairs of adjacent points are compared and a variance calculated. Values are obtained for each of the 49 possible groups for which two or more pairs pass the $1 \text{ mW}(\text{m}^2 \text{ sr cm}^{-2})$ test and are over water. For each channel, the lowest group variance is determined, an increment is added to the lowest value, and all points with group variances less than the limit are accepted. Finally acceptable values from the various channels are compared and only those acceptable for all channels are kept.

If cloud amount is the only variable that changes, then derived clear radiances should be constant. In other words, the value $I_{\text{clr}}(v_i)$ should not depend on the value of r . When mixed cloud levels are present, values of $I_{\text{clr}}(v_i)$ resulting from low values of $I_1(v_i)$ and $I_2(v_i)$ are likely to contain high clouds and thus mixed cloud levels as found in towering cumulus. As a result, values of $I_{\text{clr}}(v_i)$ are frequently in error and result in radiances that are too high, not just noisy. Each of the 196 potential values of $I_{\text{clr}}(v_i)$ is derived from radiances at two spots. The highest window channel radiance of the pair is selected and the median of these values is determined. An average value of $I_{\text{clr}}(v_i)$ for channel 6, the lowest peaking carbon dioxide channel is determined for all pairs where the window channel exceeds the median and a similar average is determined for values less than the median value. Averages are required to agree to within $\pm 0.5 \text{ mW}(\text{m}^2 \text{ sr cm}^{-1})$ or the half of the sample with window radiances less than the median is rejected and the process is repeated on the remaining points. The process is iterated until the test is passed or until the sample is reduced to fewer than ten points. In the latter case no sounding is produced.

Finally, a limit is placed on the variance of the total sample. Significant meteorological gradients can exist across the area represented by a single VTPR retrieval. These gradients result in a relatively large variance for the sample. In cloudy areas, radiances which pass the previous tests are clustered in the clearer spots. Thus a small sample usually comes from one geographical location within the total area covered by one sounding, and the expected variance is less because the meteorologically induced variance is less over the shorter distance. If the calculated variance for an array is less than 0.07 times the number of points, a sounding is produced. This particular test has no effect on the larger samples found in good areas but does eliminate questionable soundings when only a few points are included in the average.

Figure 1 is a plot of the number of rejections from all tests as a function of time. As a result of these tests, about 20 percent of the possible soundings over water are rejected as being too cloud contaminated to produce reliable radiances.

The VTPR temperature retrieval method has also been modified. Temperature retrievals are now determined from a regression of temperature as a function of radiance as described in Werbowetzki 1975. Stepwise regression is used because radiances in the various channels are correlated to the extent that numerical difficulties are experienced when all channels are used as predictors. Separate regression coefficients are produced for different categories of temperature profiles because the relationship between radiance and temperature is nonlinear over large changes in temperature. Three categories are determined from the radiance measurements. For pressures between and including 100 and 1000 mb, the window channel radiance is used to select categories. For pressure levels above the 100 mb level in height, VTPR channel 2 is used to select categories. The dividing points between categories are 95 and $111 \text{ mW}(\text{m}^2 \text{ sr cm}^{-1})$ for the window channel and 44 and $48 \text{ mW}(\text{m}^2 \text{ sr cm}^{-1})$ for channel 2.

In the discussion of the clear radiance and the retrieval methods, values of limits for various tests have been given. These values are the ones that provided the best results when they were determined. It should be noted that

these limits are subject to re-evaluation and tuning. It is unlikely that any algorithms will be changed before the launch of TIROS-N in 1978.

3. COMPARISON OF PRESENT AND PLANNED OPERATIONAL SOUNDING INSTRUMENTS

VTPR is an eight-channel instrument consisting of one channel measuring radiances in the atmospheric window at 833 cm^{-1} , one channel in the water vapor absorption region at 535 cm^{-1} and six channels in the $15\text{ }\mu\text{m}$ CO_2 band: one at 668.5 cm^{-1} responding to atmospheric temperatures between 1 and 70 mb, one at 677.5 cm^{-1} responding to temperatures between 10 and 150 mb, one at 695.0 cm^{-1} responding to temperatures between 30 and 300 mb, one at 708.0 cm^{-1} responding to temperatures between 150 and 700 mb, one at 725.0 cm^{-1} responding to temperatures between 250 and 1000 mb, and one at 747.0 cm^{-1} responding to temperatures below the 400 mb pressure level.

TIROS-N will carry three separate instruments, a Stratospheric Sounding Unit (SSU), a Microwave Sounding Unit (MSU), and an infrared sounding unit designated as High Resolution Infrared Radiation Sounding version two (HIRS/2). The HIRS/2 serves as the basic sounding instrument but is supplemented by the SSU which can measure higher levels in the atmosphere and the MSU which can produce radiances in cloudy areas.

The HIRS/2 has seven channels in the $15\text{ }\mu\text{m}$ CO_2 band. These channels peak at 668.5 , 680.0 , 690.0 , 703.0 , 716.0 , 733.0 , and 749.0 cm^{-1} , respectively, and are used to infer temperature profiles. Additional channels centered at 2190.0 , 2210.0 , 2240.0 , 2270.0 , and 2360.0 cm^{-1} in the $4.3\text{ }\mu\text{m}$ CO_2 band are used to increase the accuracy of the temperature retrievals in the lower atmosphere. Measurements in the atmospheric windows at 900.0 , 2514.0 , and 2700.0 cm^{-1} are used to determine the boundary temperature. Water vapor is obtained from three channels peaking at 1225.0 , 1345.0 , and 1488.0 cm^{-1} in the $6.3\text{ }\mu\text{m}$ water vapor absorption band and ozone is obtained from a channel peaking at $1030\text{ }\mu\text{m}$ in the $9.6\text{ }\mu\text{m}$ ozone band. Low level clouds are detected by a visible channel at $14,500\text{ cm}^{-1}$.

The SSU obtains measurements in the $15\text{ }\mu\text{m}$ CO_2 band and provides temperature information for levels above those sensed by HIRS/2. The SSU is a Pressure Modulated Radiometer (PMR) and is a successor to the Selective Chopper Radiometer (SCR) flown on Nimbus 5 and Nimbus 6 (Smith et al. 1974). Measurements of stratospheric temperatures at three levels are obtained with this instrument. Since all channels sense the stratosphere to some extent, information about this region serves as a correction to channels which respond to temperatures in the troposphere.

The MSU has three channels which peak in the oxygen absorption band (53.74 GHz , 54.96 GHz , and 57.95 GHz) plus a "window" channel at 50.3 GHz . Microwaves are virtually unaffected by clouds, but do suffer some attenuation in precipitating areas. In contrast, infrared measurements are affected by any clouds in the field-of-view. With the MSU, it will be possible to obtain soundings with limited vertical resolution in cloudy areas where it is not possible with infrared measurements.

4. OUTLOOK

Satellite soundings have been produced from infrared radiances which are affected by clouds. Techniques to handle clouds either work poorly or do not produce soundings over cloudy areas, yet these are the areas most likely to affect the forecast. Future satellite systems will use microwave measurements to sense in cloudy areas that are now being missed. They will also blend soundings with other information. For example, satellite winds derived from satellite observed cloud motions complement soundings in that wind information can be derived from cloudy areas whereas soundings are more easily obtained in clear areas. New methods are being developed to extract the information available in radiances in forms other than temperature soundings. An example is the derivation of winds from the measured radiances (Horn et al. 1976).

One approach that is currently receiving attention is that of using radiances themselves as an analysis. The radiance value for a particular channel represents an average temperature weighted over a rather broad layer of the atmosphere as determined by the transmittance. If clear radiances are available, a meteorologist can extract much of the same information from an analysis of radiances that he would be able to obtain from a thickness chart. The National Environmental Satellite Service (NESS) is currently providing information about the strength and location of the jet stream based on a manual analysis radiance from VTPR channel 3 as well as information available from other sources. Use of a man in the procedure allows detection of errors when outputs from some of the many sources of information are in conflict. Because of the many forms that information can take (cloud patterns, radiance fields, satellites, winds, etc.), a man is able to detect and correct problems in a manner that is difficult to conceive of automating on a computer. A similar procedure is being utilized to produce moisture fields from a variety of inputs including VTPR radiance data for the moisture channel. Radiances at microwave frequencies, which are relatively unaffected by clouds, are capable of determining the structure of cloud-covered areas such as the hurricane shown in figure 2 (Grody, 1977).

Accuracy is an important indicator of satellite performance. However, two factors need to be considered when looking at accuracies of satellite soundings. First, the most common source of ground truth is radiosondes which measure point values rather than the vertically and horizontally averaged values sensed by satellites. Radiosondes are also subject to errors. Second, with satellite systems, it is possible to trade accuracy for coverage. Since the meteorologically active areas cover a relatively small portion of the globe, errors in these important areas tend to get overwhelmed by areas where soundings can easily be produced but where the soundings do not provide any information about developing systems. This problem is compounded when satellite systems delete a portion of the soundings. There is no real alternative, but one must remember that producing more accurate soundings may not increase the information if the coverage is inadequate.

The first attempt at determining the accuracy of satellite soundings resulted in the collection of a set of radiosonde - VTPR match ups for March 1973. The RMS error for this data set is shown in figure 3 along with the RMS error of the initial profile used in the retrieval system at that time. Since that time, accuracies have generally improved except for the period that is required after the launch of a new satellite to collect a sample large enough to produce stable regression coefficients. The increased capabilities of future instruments with more channels and other improvements should result in increases in accuracy after the launch of TIROS-N.

Satellite sounding systems provide the only means of obtaining anything more than spot checks of features above levels usually sensed by radiosondes (14 mb). Present sounders are limited to sensing temperature in this region, but future systems will provide information on ozone, and the possibility of sensing other minor gases is being studied. Since clouds have a minimal effect on channels used to sense these regions, their effects are easily removed by cloud correction techniques and some channels require no correction. Because there has been a lack of comprehensive data for these regions, dynamics of this region and interaction between the troposphere and stratosphere are not well known. The daily global coverage provided by satellites will provide a means of proving or disproving the various theories which exist. With the increasing concern about climate and climate changes, satellite measurements at these altitudes will continue to be a valuable source of information.

5. SUMMARY

Initial attempts at using satellite radiances resulted in the production of temperature profiles similar to those produced by radiosondes. While increases in accuracy have been made and additional increases are expected to result from increased instrument capabilities, it has been recognized that the production of level temperatures is not consistent with the average temperature that is

represented by the radiances and that other methods of extracting the information make better use of the broad coverage and horizontal consistency which characterize satellite radiances in the cloud-free regions of the atmosphere. Use of satellite radiances to derive parameters such as thickness values, winds, ozone, or water vapor is expected to increase.

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TABLE I. OPERATING PERIODS OF NOAA SATELLITES

NOAA 2	26 October 1972-----17 March 1974
NOAA 3	17 March 1974-----1 July 1974
NOAA 2	1 July 1974-----15 October 1974
NOAA 3	15 October 1974-----17 December 1974
NOAA 4	17 December 1974-----14 September 1976
NOAA 5	14 September 1976-----Present

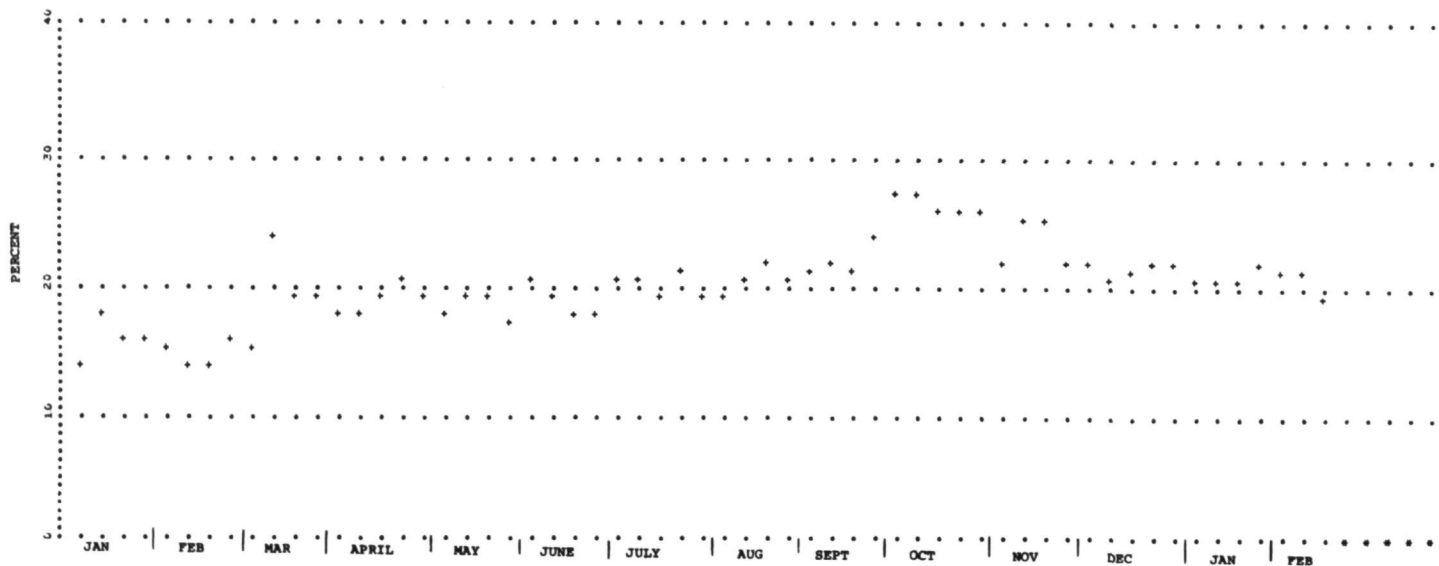
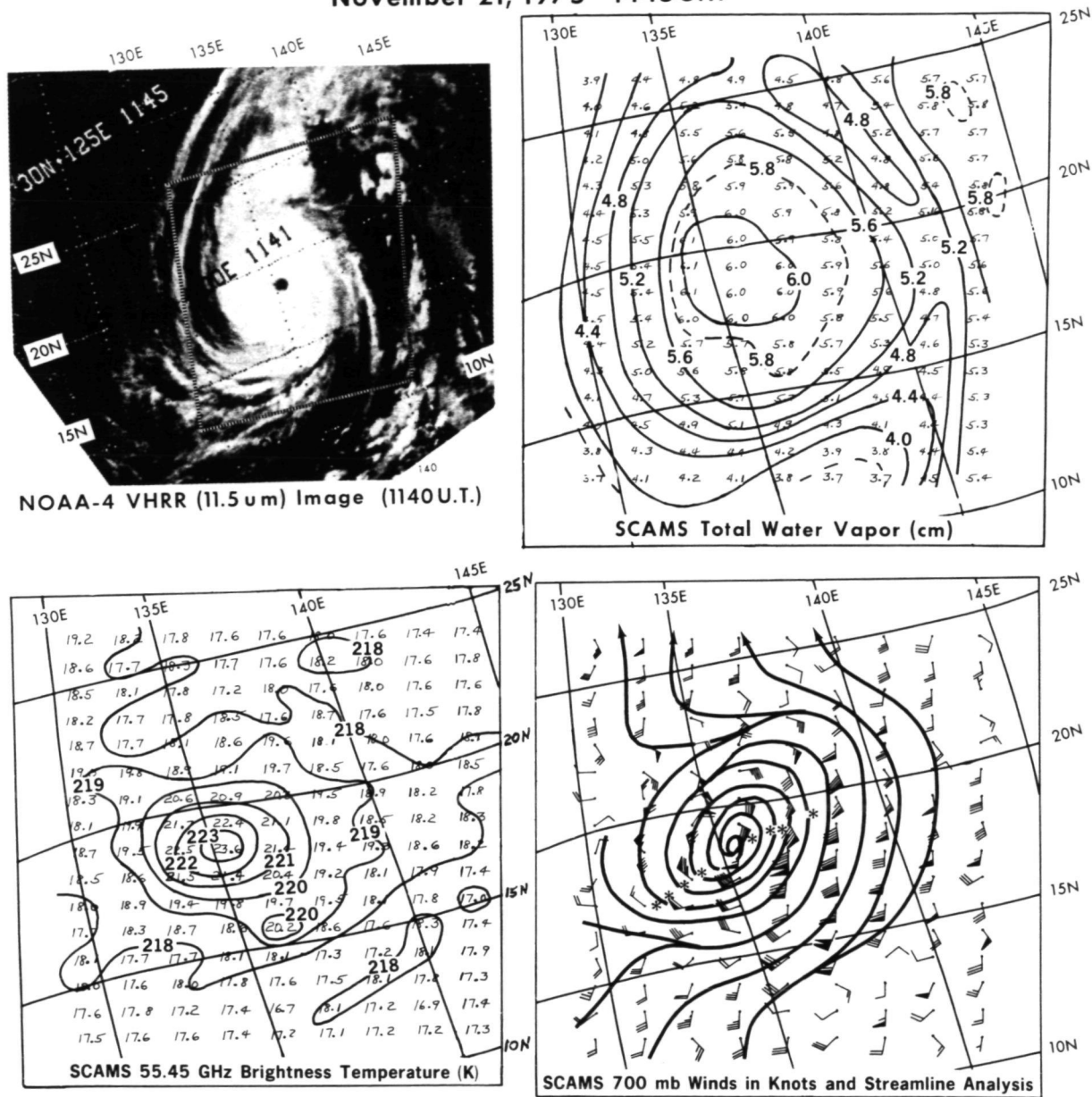


FIGURE 1. PERCENT OF POSSIBLE RETRIEVALS REJECTED AS BEING TOO CLOUDY BY THE CLEAR RADIANCE ALGORITHM BY WEEKLY INTERVALS FOR THE PERIOD FROM JANUARY 1976 THROUGH MARCH 1977.

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November 21, 1975 1445 U.T.



Typhoon June Viewed by a Scanning Microwave Spectrometer - SCAMS

FIGURE 2. MICROWAVE MEASUREMENTS OF TYPHOON JUNE DEMONSTRATING THE ABILITY OF MICROWAVE MEASUREMENTS TO PROVIDE METEOROLOGICAL INFORMATION IN CLOUDY AREAS.

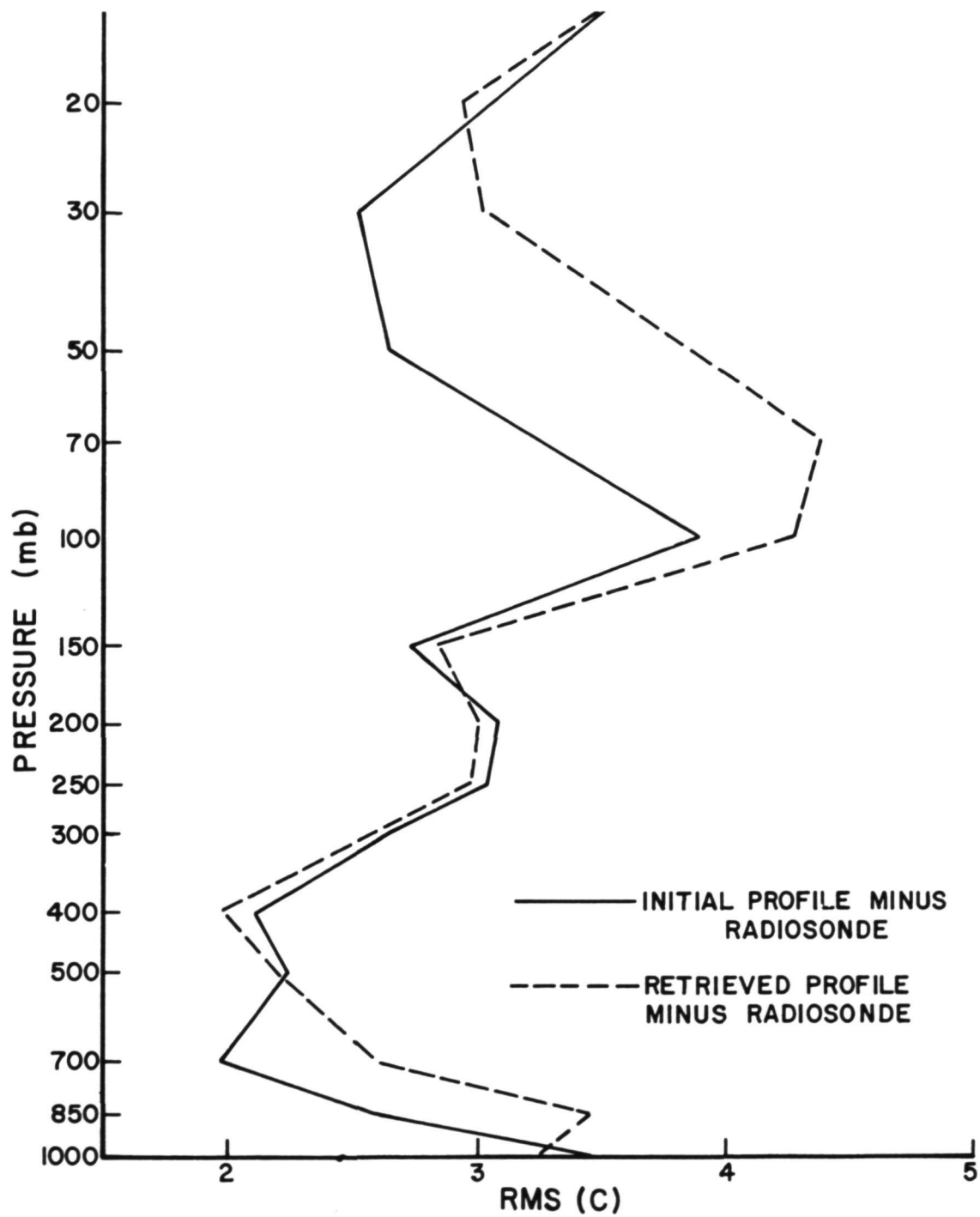


FIGURE 3. DIFFERENCES BETWEEN SATELLITES SOUNDINGS AND RADIOSONDES FOR NEARLY COINCIDENT AND NEARLY SIMULTANEOUS SOUNDINGS COLLECTED DURING MARCH 1973.

A MULTICHANNEL PASSIVE MICROWAVE ATMOSPHERIC
TEMPERATURE SOUNDING SYSTEM

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ABSTRACT

The development of a small, lightweight, low-power, seven-channel passive microwave radiometer system for use on the Defense Meteorological Satellite Program (DMSP) is described. This 50-60 GHz sensor system operates in the region of an intense atmospheric oxygen absorption band to provide atmospheric temperature profiles to 30 kilometer altitudes on a global basis.

1. INTRODUCTION

Knowledge of the temperature distribution of the atmosphere on a global scale is a key factor in the prediction of various weather parameters by meteorologists. Although some such profile information is currently available from radiosonde, rocketsonde and infrared atmospheric sounding systems, each of these systems has its obvious limitations. This paper describes a multichannel passive microwave radiometric sensor system that has been developed (Ref. 1) for use on the Defense Meteorological Satellite Program (DMSP) to gather such temperature distribution information on a global basis. Atmospheric temperatures for pressure levels of 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20 and 10 mb; 14 thicknesses between these levels; and the temperature and pressure of the tropopause will ultimately be provided.

The radiometric characteristics of the atmosphere are determined primarily by the absorption and emission characteristics of the oxygen molecule in the 50-60 GHz band of the frequency spectrum. Since the mixing ratio of oxygen is constant in the atmosphere, the contribution of a particular layer of the atmosphere to the total radiation detected by a spaceborne radiometer operating in this frequency range is primarily controlled by the air temperature and the product of two competing factors — namely, the emission per unit volume, which decreases monotonically with height due to the decreasing air density, and the transmission factor of the atmosphere above the layer under consideration, which increases with height. The product results in a function (the weighting function) which typically peaks at some height and decreases with distance away from the peaking altitude. By choosing frequencies with different absorption coefficients, weighting functions emphasizing radiances from preselected atmospheric layers may be obtained. The problem of profiling the temperature of the atmosphere then reduces to finding the most probable profile which, when weighted by the appropriate weighting functions, produces the measured brightness temperature values of the selected frequencies.

Since the underlying earth surface also contributes to the detected radiation at those frequencies responding to the lowest portion of the atmosphere, the software used in the extraction of atmospheric information from the microwave data must be designed to eliminate the effects of the surface. A unique, highly efficient algorithm that accounts for varying surface emissivities, lower tropospheric effects, and terrain height variability has been developed to do this (Ref. 2).

Specification of the altitudes at which the weighting functions are to peak and the full width half maximum of the weighting functions establishes the center frequency and bandwidth of the individual sensor channels. At the higher peaking altitudes where the pressure broadening is reduced and the line widths are extremely narrow, both frequency and bandwidth

selections must reflect a consideration of both software and hardware roles. Consequently, narrow bandwidths and a high degree of frequency stability are required at these altitudes.

Profiling of the atmosphere from sea level to an altitude of 30 kilometers has resulted in the selection of seven channels ranging in frequency from 50.5 GHz to 59.4 GHz as shown in Table I. A requirement for a maximum calibration uncertainty of 1 K and maximum NETD for the various channels of 0.4 to 0.6 K has established the electrical performance requirements of the sensor system. Stringent weight, power and size limitations of 11.5 kg, 18 watts and 0.20 x 0.36 x 0.41 meters respectively, have also restricted the physical characteristics of the sensor.

This paper describes the design and performance of a lightweight, low-power, seven-channel radiometer sensor system that satisfies these requirements.

2. SYSTEM CONFIGURATION

The Multichannel Passive Microwave Temperature Sounder System, shown in Figure 1 and in simplified block diagram form in Figure 2, consists of a mechanically scanned reflector antenna, a stepper motor/gear antenna drive, a seven-channel superheterodyne receiver, and signal processing/timing circuitry. Precise total system inflight calibration is achieved by viewing known radiometric temperatures through the antenna system. An accurately known ambient load (300 K nominal) and the cosmic background (2.7 K) are used for this purpose. These absolute calibration points make it possible to determine the sensed antenna temperatures in an absolute manner.

The mechanically scanned reflector antenna system shown in Figure 3 consists of a lens-corrected, corrugated feed horn, a shrouded reflector and an orthogonal mode transducer (OMT). It provides a planar scan by a rotation of the reflector surface; this allows the antenna feed system to remain fixed. A metallic hood shrouds the reflector to eliminate back radiation and provides a guided interface to the calibration system. A thermal shroud is also incorporated into the design to shade the inflight calibration source apertures during scan and reduce thermal gradients at the calibration apertures.

As seen in Figure 4, the antenna beam is step-scanned through seven discrete earth-looking positions at a fixed, programmed rate, then is rapidly rotated, first to the warm calibration reference, then to the cold calibration reference, before the scanning sequence is repeated. Key scan parameters are detailed in Table II. Because the calibration paths are characterized by low reflective and dissipative losses, the equivalent antenna input temperature during calibration can be accurately determined.

The antenna input brightness temperature (T_i) is determined from the relationship

$$T_i = T_H - \frac{T_H - T_C}{V_C - V_H} (V_i - V_H)$$

where T_H = warm calibration input temperature, T_C = cold calibration input temperature, V_H = output voltage during warm calibration, V_C = output voltage during cold calibration, V_i = output voltage corresponding to T_i . (The modulator temperature is not required in the above expression for T_i because of the thermal characteristics of the instrument and the periodicity of calibration.)

Signals in the 50 to 60 GHz frequency range are received by the antenna system and subsequently split into two orthogonal polarizations by an orthogonal mode transducer (OMT). The use of an OMT allows both orthogonal polarizations to be utilized, thereby establishing the initial level of frequency channelization. One polarization is used for the lower altitudes, Channels 1-4; the other polarization is used for the upper altitudes, Channels 5-7.

From the OMT the received signals are applied to a unique broadband, low-loss dual resistive vane modulator. This device serves to chop the input signal and does not, as mentioned previously, influence the determination of T_i . With an attenuation that exceeds

50 dB and an insertion loss of less than 0.3 dB over the entire frequency band this modulator approximates an ideal switch and thus avoids the switching errors associated with ferrite type modulators.

After modulation, one of the signals is applied to an RF diplexer, the other to an RF bandpass filter. The RF diplexer splits the signal into two bands containing Channels 1, and 2, 3, and 4 frequencies, respectively. Specifics of the channel peaking altitude, frequency, bandwidth and NETD were shown previously in Table I. The Channel 1 band is down-converted, amplified, filtered, and subsequently detected. Down-conversion is accomplished in a broadband balanced mixer in which GaAs Schottky-barrier diodes are used. Similarly the Channel 2, 3, and 4 band is down-converted and amplified in a common mixer-IF amplifier and then applied to an IF triplexer which splits the signal into three discrete channels of information, which are then detected by square-law detectors.

The signal from the other half of the dual-vane modulator, i.e., the signal applied to the RF bandpass filter, contains Channels 5, 6, and 7. The filter serves to remove the corresponding image frequencies. After filtering, these channels are treated in a manner identical to that used for Channels 2, 3 and 4. The overall receiver bandwidth and channelization characteristics are shown in Figure 5.

A single frequency stabilized Gunn oscillator is used as the local oscillator to conserve power and weight. The frequency of the oscillator was chosen such that potentially detrimental EMI signals would fall outside the filtered IF passbands. Stability specifications for the oscillator are based on the profiling accuracy required over a two-year life of the instrument. The fundamental Gunn oscillator is matched and locked to a high-Q Invar cavity to achieve the required long-term frequency stability. Since the stabilization network is totally passive, long-term reliability is assured.

After detection, the seven channels of information are processed by individually programmable stepped automatic gain control (SAGC) attenuators. The SAGC maintains the system gain such that the analog-to-digital converter resolution capability is optimized for any possible variation in the predetection gain. After gain conditioning, the signals are processed by individual synchronous demodulator integrate-and-dump circuits. These integrated signals are then multiplexed into a common 12-bit analog-to-digital (A/D) converter and subsequently demultiplexed into data storage and readout circuits. Critical points throughout the system are thermally monitored by temperature sensor readout channels which are multiplexed into the A/D converter for subsequent readout.

The system operates in both a synchronized mode and an independent or automatic mode. In the synchronized mode, an external synchronization signal causes the sensor to initiate scanning in a step-synchronized fashion with an onboard IR sensor. When the system is operated in the automatic mode, antenna scanning is completely independent of the external synchronization signal.

3. CALIBRATION

As described previously, the inflight calibration system, shown schematically in Figure 6, consists of two noise sources. A cold path views the cosmic background (2.7 K) for one calibration point and a built-in "warm" load (≈ 300 K) is observed for the other calibration point. The radiometer (including the antenna) is calibrated once during each 32-second scan cycle.

The inflight calibration system is a well-matched, closed-path configuration with very low dissipative wall losses. A shroud on the reflector allows direct coupling to both the cold path and warm load. The cold path is an oversize circular transmission line that is used to restrict the radiometer field of view so that extraneous input signals due to both the surrounding spacecraft and the earth's atmosphere are minimized. Due to the location of the sensor on the spacecraft it is not possible for the sensor antenna to view the sky directly. Therefore, it is necessary to utilize a reflecting miter bend in the cold path to direct the antenna pattern in the proper direction. The warm load is an extended microwave radiator made up of a large number of tapered absorbing sections and is designed to provide a stable blackbody temperature source at approximately 300 K. An accurate measurement of the surface temperature of the load is provided as a result of the warm load thermal design. A

shroud allows direct coupling to the antenna and a sun shield located on the antenna reflector prevents the warm load from viewing the sun, thereby enhancing the thermal stability of this load.

Precision primary temperature standards are used for laboratory calibration of the instrument. In these standards the surface temperature of the microwave load is measured very precisely and the reflection characteristics are extremely low. Two primary standards stabilized at approximately 78 K and 300 K are used to calibrate the radiometer in the laboratory under stable thermal-vacuum conditions. A remotely controlled, semiautomatic primary standard transport mechanism, Figure 7, is used in conjunction with the radiometer to accomplish the calibration process. Once the radiometer has been calibrated with at least two primary standards, the calibration and linearity of the instrument is verified by viewing additional standards at temperatures between the calibration extremes.

4. PACKAGING DESCRIPTION

To achieve the high packaging density required by system weight and size limitations, a compartmentized design has been used. As shown in Figure 8, the RF components of the receiver and the antenna feed horn are mounted to a honeycomb shelf. Use of a shelf allows the antenna reflector to be mounted high in the instrument, thereby avoiding radiation pattern interference from the instrument walls. Use of the shelf also allows the feed horn, orthogonal mode transducer and the modulator to be mounted close together on the same surface, reducing RF losses. A higher than usual packaging density for RF components is achieved by packaging the three mixers and IF amplifiers in three parallel routes on each side of the modulator. The IF filter and triplexers, as well as the seven detector/preamplifiers are located in the forward part of the lower compartment. All post detection circuitry is mounted on printed circuit cards located in the rear portion of this lower compartment.

5. SYSTEM PERFORMANCE

The overall measured performance of the sensor system is summarized in Table III. The final size, weight and power consumption of the sensor system are 0.2 x 0.28 x 0.41 meters, 11.2 kilograms, and 14.2 watts respectively. An antenna beam efficiency in excess of 95.8 percent and a beamwidth of 14.4 degrees or less were achieved at all seven frequencies and all seven beam positions.

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2. Rigone, J. L. and A. P. Stogryn, "Data Processing for the DMSP Microwave Radiometer System," Eleventh International Symposium on Remote Sensing of Environment, April 1977, Poster Session P-123.

TABLE I. CHANNEL PARAMETER REQUIREMENTS

Channel	Peaking Height (km)	Frequency (GHz)	Bandwidth (MHz)	NETD
1	0 (window)	50.5	400	0.6
2	2	53.2	400	0.4
3	6	54.35	400	0.4
4	10	54.9	400	0.4
5	30	58.4	115	0.5
6	16	58.825	400	0.4
7	22	59.4	250	0.4

TABLE II. KEY SCAN PARAMETERS

Scan Type	Cross-Track Nadir
Cross-Track Positions	7
Calibration Positions	2-Cosmic Background and ≈ 300 K
Total Cross-Track Scan	$\pm 36^\circ$
Total Scan Period	32 Seconds
Dwell Time (Cross-Track and Calibration Positions)	2.7 Seconds

TABLE III. MEASURED PERFORMANCE

Channel No.	Center Freq GHz	Bandwidth MHz	NETD K	Calib Uncertainty K
1	50.5	400	0.32	0.25
2	53.2	400	0.24	0.21
3	54.35	400	0.36	0.24
4	54.9	400	0.22	0.13
5	58.4	115	0.39	0.06
6	58.825	400	0.29	0.24
7	59.4	250	0.31	0.13

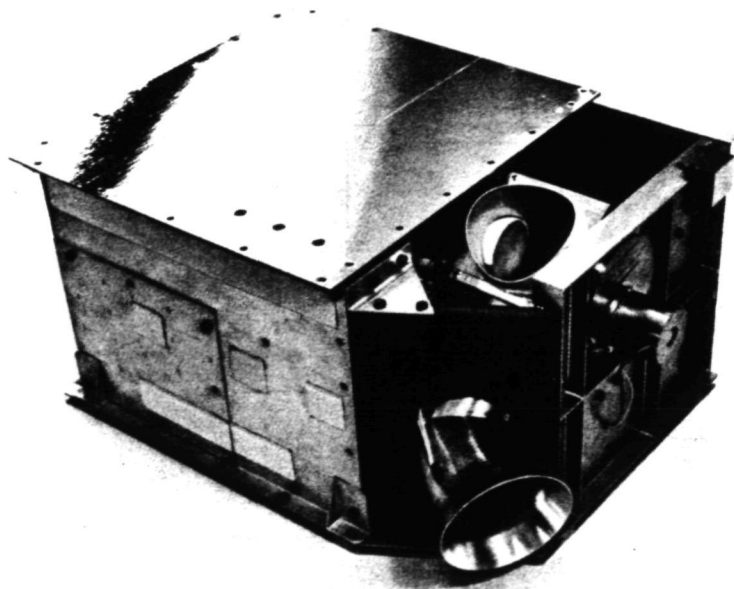


Figure 1. Multichannel Passive Microwave Temperature Sounder System

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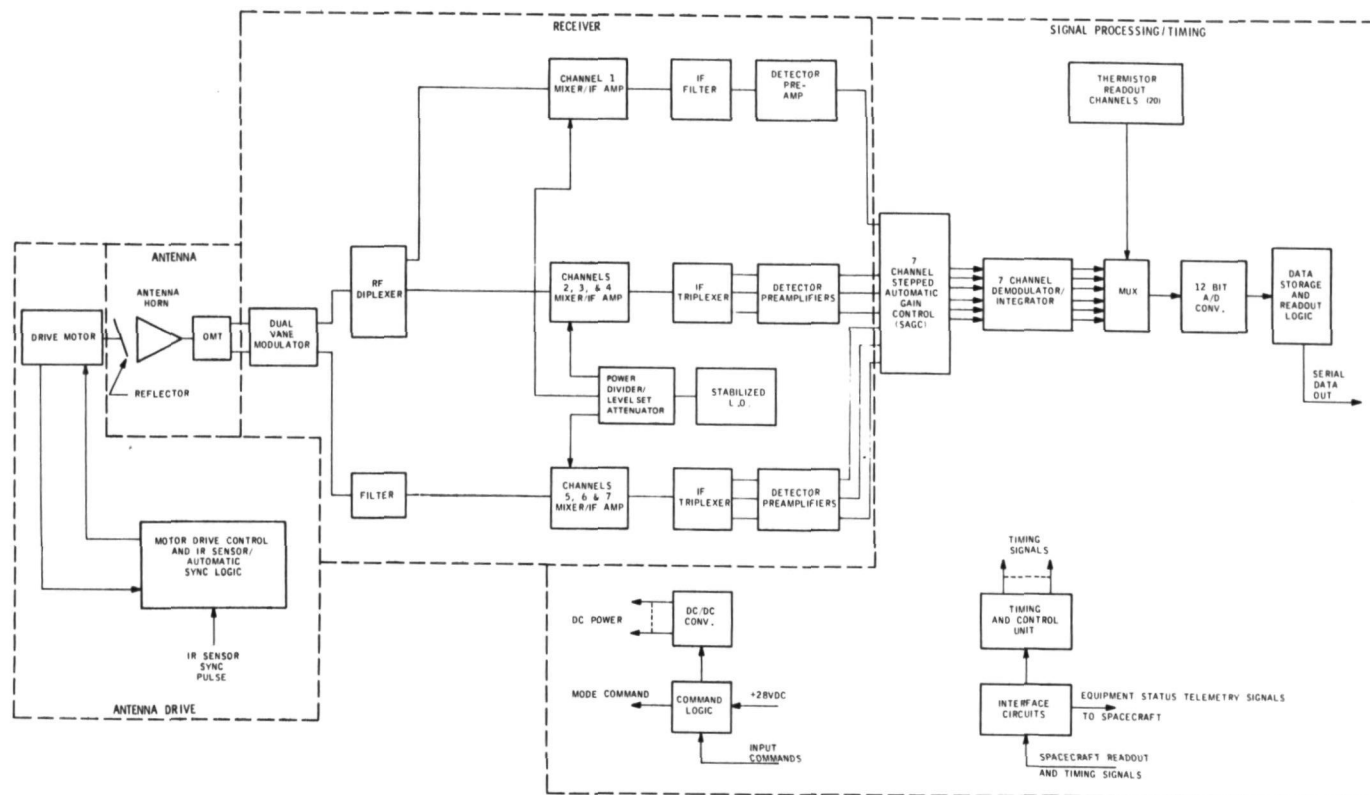


Figure 2. Simplified System Block Diagram

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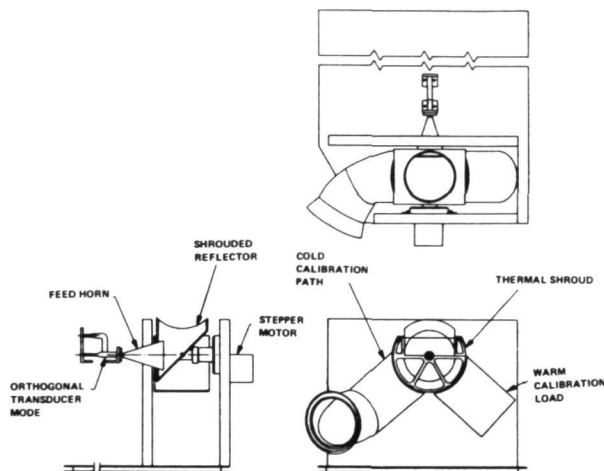


Figure 3. Antenna Subsystem

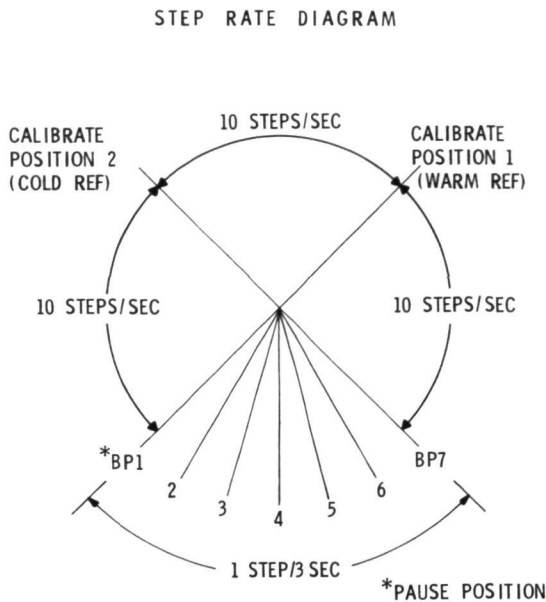


Figure 4. Calibration and Scanning Geometry

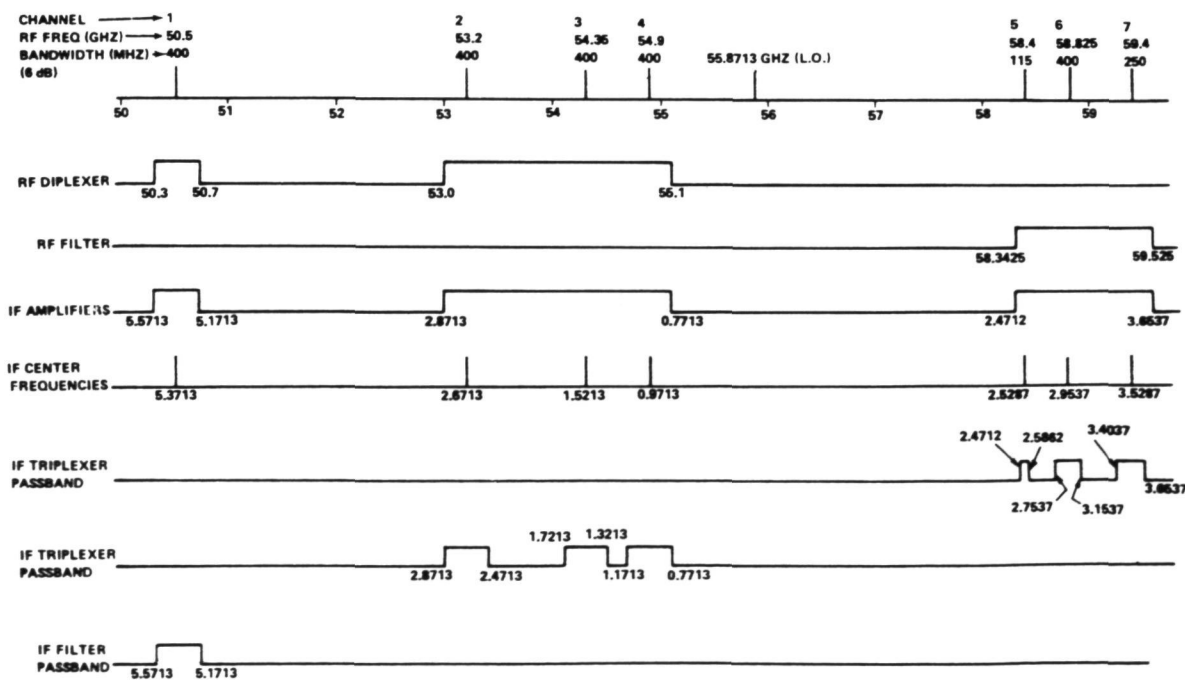


Figure 5. Receiver Bandwidth and Channelization

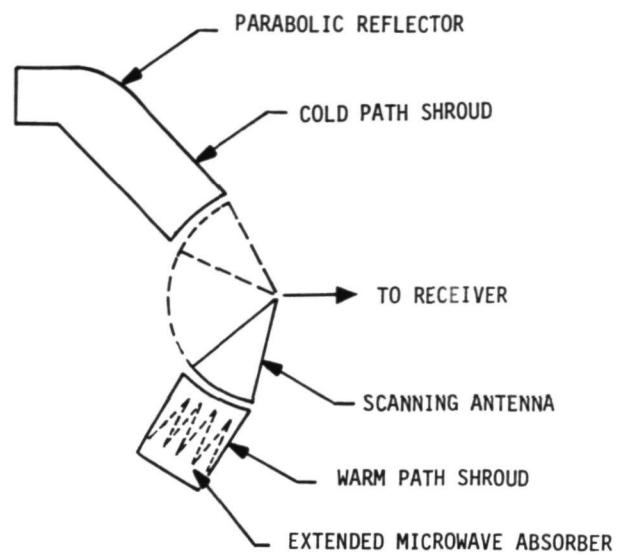


Figure 6. Calibration Subsystem

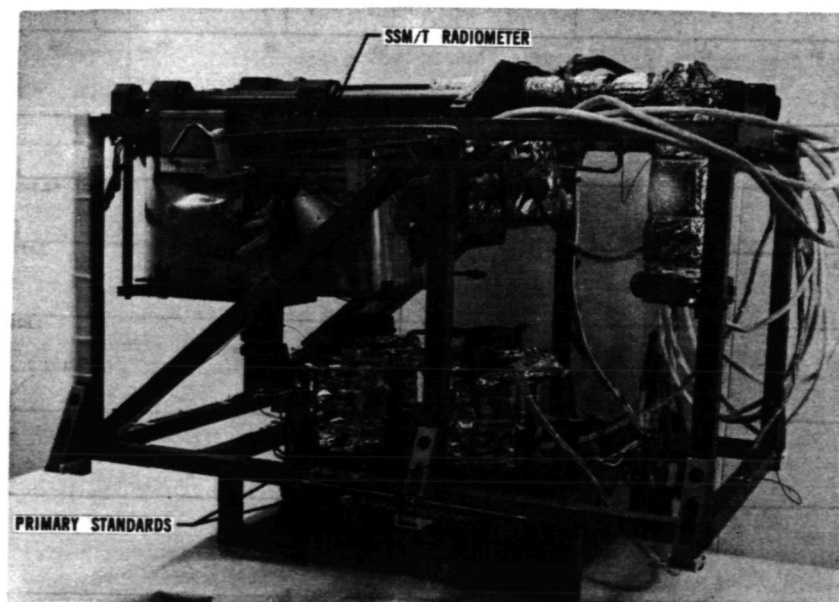
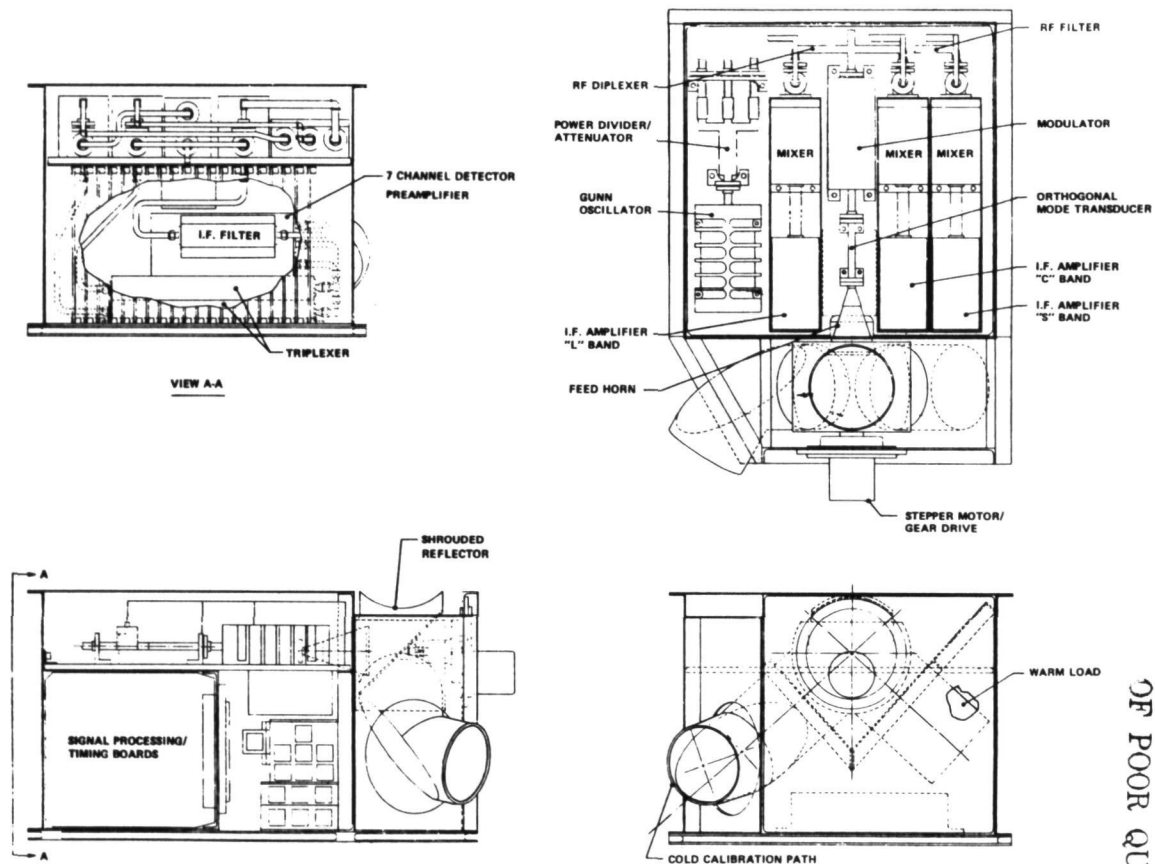


Figure 7. Primary Standard Transport Unit



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Figure 8. Radiometer Packaging

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MAPPING DIURNAL VARIATIONS IN CHLOROPHYLL "a",
TRANSPARENCY, AND SURFACE TEMPERATURES IN THE NEW YORK BIGHT

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SUMMARY

An aircraft multispectral imaging sensor was used to map several water parameters in the New York Bight during different times of the diurnal tidal cycle. By a suitable operation on two or more channels of spectral data in the visible region, both transparency and chlorophyll "a" variations can be quantitatively mapped. Surface chlorophyll "a" variations between 1 mg/m³ to 30 mg/m³ were successfully mapped as verified by independent ship measurements. Remotely sensed transparency measurements within the Bight were referenced to secchi disk depths on the basis of control stations. Since the multispectral scanner contains data in the visible, near IR, and thermal IR in complete registration surface temperatures were also available from the same data set. Eight passes at 10,000 feet were flown in radial lines to cover the New York Bight area at times corresponding to an incoming tide and an outgoing tide. Complex circulation patterns in the distributions were easily recognized. Dye drops were also mapped to support ship measurements and model predictions of circulation.

Large area demonstration of the multiple parameter mapping with multispectral imagers foretell the potential of similar satellite sensors for monitoring large coastal circulation systems and understanding effects of local discharges on environmental quality in neighboring coastal zones.

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EVALUATION OF CHANGE DETECTION TECHNIQUES
FOR MONITORING COASTAL ZONE ENVIRONMENTS*

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ABSTRACT

Development of satisfactory techniques for detecting change in coastal zone environments is required before operational monitoring procedures can be established. In an effort to meet this need a study was directed toward developing and evaluating different types of change detection techniques, based upon computer-aided analysis of Landsat multispectral scanner (MSS) data, to monitor these environments.

The Matagorda Bay estuarine system along the Texas coast was selected as the study area. Land use within this area is divided principally among agriculture, range-land, urban, industry, recreation and large marsh-covered tracts.

Four change detection techniques were designed and implemented for evaluation: a) post classification comparison change detection, b) delta data change detection, c) spectral/temporal change classification, and d) layered spectral/temporal change classification. Each of the four techniques was used to analyze a Landsat MSS temporal data set to detect areas of change of the Matagorda Bay region.

The post classification comparison technique reliably identified areas of change and was used as the standard for qualitatively evaluating the other three techniques. The layered spectral/temporal change classification and the delta data change detection results generally agreed with the post classification comparison technique results; however, many small areas of change were not identified. Major discrepancies existed between the post classification comparison and spectral/temporal change detection results.

INTRODUCTION

Our nation's coastal zones are locales of unending change. Effective inventorying and monitoring of these changes are required for resource management. Conventionally, monitoring of these areas has been accomplished either by local on-site surveys or photointerpretation of aerial photographs, and change detection has required the manual comparison of various single date analyses. For large area inventories, both local surveys and photointerpretative techniques require large data collection efforts and are time consuming and subjective in nature.

*This work was accomplished under the National Aeronautics and Space Administration Contract No. NAS9-14016. Journal Paper No. 6689 Purdue University, Agricultural Experiment Station.

Consequently, it would be desirable to develop and implement a computerized change detection procedure suitable for large area inventories.(1) However, before operational monitoring procedures can be established, satisfactory computer-aided change detection techniques must be developed. In order to meet this need, this study was initiated toward developing and evaluating various change detection techniques based upon computer-aided analysis of Landsat multispectral scanner (MSS) data to monitor coastal zone environments.

STUDY SITE

A portion of the Matagorda Bay estuarine system located along the Texas coast was selected for this study. This area is characterized by a great diversity in geography, resources, climate, waterways and estuaries similar to the entire coastal zone of Texas. Also, it is subjected to numerous natural hazards such as shoreline erosion, land surface subsidence, stream flooding, hurricane tidal surges and active surface faulting. Lower elevations of the coastal area are covered with marshes and swamps, and the standplains are chiefly sandy materials. The coastal upland areas consist mainly of clay and mud materials deposited as sediments during the Pleistocene era. Land use within this study site is divided principally among agriculture, rangeland, urban, industry, recreation and large marsh-covered tracts.(2)

APPROACH

Data

Landsat MSS data collected on November 27, 1972 and February 25, 1975, were used as the principal data sources for this study. These data were geometrically corrected (i.e., rotated, deskewed and rescaled)(3), overlaid and precision registered to ground control points selected from appropriate U.S. Geological Survey (USGS) 7½ minute topographic quadrangle maps. This procedure produced a multirate eight-channel data set at a scale of 1:24,000 and registered points in the data to their exact ground position. Reference data utilized to support the analysis of the Landsat data included 1970, 1971 and 1975 color and color infrared aerial photography, Geologic Atlases compiled by the Texas Bureau of Economic Geology, and Spectral Environmental Classification overlays produced by Lockheed Electronics Corporation.

Single Date Analysis

A non-supervised approach utilizing the maximum likelihood classifier as implemented by LARSYS (4) was used to produce a classification for each date for areas corresponding to individual USGS 7½ minute quadrangle maps. The resultant classifications included informational categories of agriculture, rangeland, grasslands, wooded areas, swamp timber, fresh and brackish marshes, mud and sand flats, beach and beach ridges, residential areas, and open water classes. This initial study demonstrated that digital analysis of Landsat MSS data could be used to inventory the coastal environment effectively.(5)

Change Detection Analysis

Four specific test sites were selected within the Matagorda Bay estuarine system for implementation and evaluation of change detection techniques. These were the areas included in the Austwell, Port Lavaca-E, Port O'Connor and Pass Cavallo-SW USGS 7½ minute topographic quadrangles.

Four techniques for detecting change were designed and implemented for evaluation (6): a) post classification comparison, b) delta data change detection, c) spectral/temporal change classification, and d) layered spectral/temporal change. All four techniques require registration of the data prior to analysis for change. A brief description of each technique follows.

Post Classification Comparison (7)

Post classification change detection is based on the comparison of independently produced spectral classifications. The comparator is simply a processor that "compares" two standard LARSYS classifications utilizing class pairs specified by the analyst and generates a results tape indicating areas of change. Thus, the change classes derived are defined by the analysts rather than being identified spectrally using pattern recognition techniques. By properly coding the classification results for times t_1 and t_2 , the analyst can produce change maps which show a complete matrix of changes. In addition, selective grouping of classification results allows the analyst to observe any subset of changes which may be of interest.

Delta Data Change Detection (8)

The delta data change detection technique is based upon the classification of a multispectral difference data set. A delta (subtraction) transformation combines two n-channel multispectral data sets obtained at different times and produces a multispectral delta data set having n-channels. Since the LARSYS system assumes all data samples used are non-negative, a bias is added to each difference so that the resulting delta data is non-negative. Thus, the complete transformation is simply:

$$\delta X_{ij}^k = X_{ij}^k(t_2) - X_{ij}^k(t_1) + b_k$$

Where: X_{ij}^k = Multispectral value for channel k; $i, j = 1, \dots, N$ assuming an $N \times N$ image
i = Row
j = Column
k = Channel
 b_k = Bias for Channel k
 t_1 = First date
 t_2 = Second date

This approach assumes that specific changes from one time to another will produce a non-negative result which can be detected either by examining the images directly or by first classifying the delta data, then examining the results displayed in image form. The classification method is similar to that for classification of ordinary multispectral data; however, it emphasizes classification of multispectral change instead of changes in multispectral classification.

Spectral/Temporal Change Classification

This technique is based upon a single analysis of a multirate data set to identify change. In a two-date Landsat data set, eight channels of data would be analyzed using standard pattern recognition techniques. By using data sets collected under similar conditions at nearly the same day of the year but from different years, one would expect that classes where change is occurring would have statistics significantly different from where change had not occurred and could be so identified.

Layered Spectral/Temporal Approach (9,10,11)

The layered or decision tree classifier is essentially a maximum likelihood classifier using multi-stage decision logic. It is characterized by the fact that an unknown sample can be classified into a given class using one or more decision functions and channels in a successive manner. This classification strategy can be most easily illustrated by a tree diagram consisting of a root node, a number of non-terminal nodes or decision stages (layers) and terminal nodes (i.e., the decision making procedure terminates with the unknown sample being assigned to the class at a terminal). A non-terminal

node is an intermediate decision, its immediate descendent nodes representing the possible outcomes of that decision.

To specify a decision tree uniquely, two sets of information are necessary: a) how the terminal and non-terminal nodes are linked and b) the decision functions and channels of all the non-terminal nodes. The decision tree can be constructed manually or by an automatic optimized logic tree design procedure. For the purpose of change detection a hybrid of these two procedures was utilized. Decision trees for each of the two dates, t_1 and t_2 , were obtained automatically and then manually linked introducing within the tree a logic for detecting the desired changes.

RESULTS

A quantitative evaluation of the change detection procedures developed would require the collection of a comprehensive set of reference data (ground observations and/or aerial photography) coincident with the Landsat overpass. However, coincident reference data were not available for this particular project (i.e., reference data for the 1972 Landsat data consisted of aerial photography collected in 1970, 1971). Thus, only a qualitative evaluation of the results of the change detection techniques could be accomplished.

Since the comparison of results from two single date classifications is the basis of the post classification comparison change detection procedure, the results of this technique were used as the standard for evaluating the results from the other three procedures. Correlation of the unsupervised spectral classes with informational classes was accomplished by:

- a) associating the spectral classifications with aerial photography when appropriate,
- b) utilizing a ratio, $A = \frac{V}{IR}$ calculated for each spectral class, where V is the relative intensity of the mean spectral values of the visible wavelengths {(0.5 to 0.6 μ m) + (0.6 to 0.7 μ m)} and IR is the relative intensity of the mean spectral values of the reflective infrared wavelengths {(0.7 to 0.8 μ m) + (0.8 to 1.1 μ m)} and
- c) by summing the relative intensity values ("summed response") of all four bands to determine the magnitude of relative spectral responses for each spectral class.

By observing the aerial photography, the ratio A and the summed response, the analyst delineated major vegetation and land use categories within the coastal zone area. Results from the Port O'Connor quadrangle, which are representative of the four test areas, are presented for illustrative purposes.

Utilizing the post classification comparison technique, the November 1972 and February 1975 dates for the Port O'Connor test site were classified into 25 and 23 spectral classes, respectively. These classes were grouped into 6 ecological categories: a) urban, b) woody/herbaceous vegetation, c) submerged vegetation and tidal flats, d) spoil areas, e) water and f) burned areas. The logic comparator was constructed to identify the class pairs listed in Table I. The map produced by this comparison (Figure 1) illustrates the areas of change.

Cluster analysis of the delta data set produced 13 delta spectral classes representing seven identifiable informational classes (Table II). These information classes were not in a 1:1 correspondence with the post classification comparison classes but rather were dispersed over a number of the classes. However, visual inspection of the delta data change results map showed a good general agreement between the post classification comparison and delta data change results in that the no-change water/land interfaces and the delineation of burn areas were in close agreement. Pixels classified into the mixed and urban change classes were widely dispersed through the land and marsh areas. This situation may be related to the inherent difficulty of using present

Landsat resolution and wavelength bands to discriminate reliably among certain surface features and not to the change detection procedure.

To evaluate the spectral/temporal approach to detecting change, three areas from the eight-channel data set were clustered to identify potential change classes. These included the agricultural region, intercoastal waterway and the barrier island, areas where change was expected to be occurring. Statistics developed during clustering were used to identify potential change classes using the following empirically-derived criteria:

a change class was probable if the ratio ($A = \frac{V}{\bar{I}R}$) for each of the two dates differed by more than 0.30, and the summed response differed by more than 25.0.

Fifty-two spectral classes were identified resulting in five information classes (Table III), four of which represented change.

Comparison of the results of the spectral/temporal approach to the post classification comparison technique indicated major disagreement. Pixels classified into the woody to woody class by the post classification comparison technique were classified as vegetation to soil, and soil to vegetation change classes (Table III) by the spectral/temporal change detection technique. Similarly, the pixels classified into the submerged-submerged, any non-submerged-submerged and water-water classes were classified as a water to soil change class. Only the burn change class agreed well with the post classification comparison change results.

Detection of change using the layered spectral/temporal approach involved developing a layered decision tree based upon time₁ statistics for time₁ (November 1972) and attaching a layer decision tree based upon time₂ statistics for time₂ (February 1975) to the appropriate terminal nodes of time₁, producing a "change decision tree". Results of this procedure produced 47 spectral classes, and 18 informational classes, 10 of which were change classes (Table IV).

Results of the layered spectral/temporal approach were in good agreement with those obtained by the post classification comparison procedure. Burn areas and the no-change land/water interfaces were very similar. Urban areas were well identified; however, occasionally the dredged spoil areas along the intracoastal waterway were placed into the urban class due to the similarities in spectral response. Some of the confusion between classes was attributed to the trimming of the decision trees (which was necessary to accommodate the tree in computer memory).

CONCLUSIONS

In devising a change detection procedure one property to consider is the relative complexity of the method; all other things being equal, a simpler approach would be more desirable for implementation reasons. However, more complex methods may have more performance potential in the long run. On a scale of increasing complexity the four methods investigated may be ordered as follows:

1. Delta data method. This method requires only a simple subtraction followed by a single classification.
2. Post classification comparison. This method requires two separate classifications followed by a logical comparison.
3. Spectral/temporal classification. While this method requires only a single classification, it is a vastly more complex one, requiring more classes and probably more features.
4. Layered spectral/temporal classification. This method involves not only a complex classification but also a priori knowledge of the

logical interrelationship of the classes as well.

In a change detection analysis, change detection error can arise from classification error at date one, date two or both times. To evaluate precisely the results of various change detection procedures, comprehensive ground information must be available to identify any error condition.

Since adequate reference data for a thorough evaluation was not available, the post classification comparison change detection results were used as the standard for qualitative evaluation of the results from the other three procedures. Areas of major change were reliably identified by the post classification comparison technique. This is due in part to the fact that the analysis procedures required are routine and quite well understood.

Evaluation of the other three change detection techniques indicates the following:

a) The delta data change detection method may be too simple to deal adequately with all the factors involved in detecting change in a natural scene. Too much information may be discarded from the data in the subtraction process whereby only the four band difference data remains from the two sets of original four bands. Images created from the delta data may be quite useful, however, in qualitatively assessing change by image interpretation.

b) The spectral/temporal and layered spectral/temporal change detection methods cannot be ruled out at this point as each appears to have undeveloped potential. The layered spectral/temporal change detection results in particular showed best agreement with the post classification comparison results. More complex methods usually require more carefully drawn data inputs together with greater user understanding to achieve their potential.

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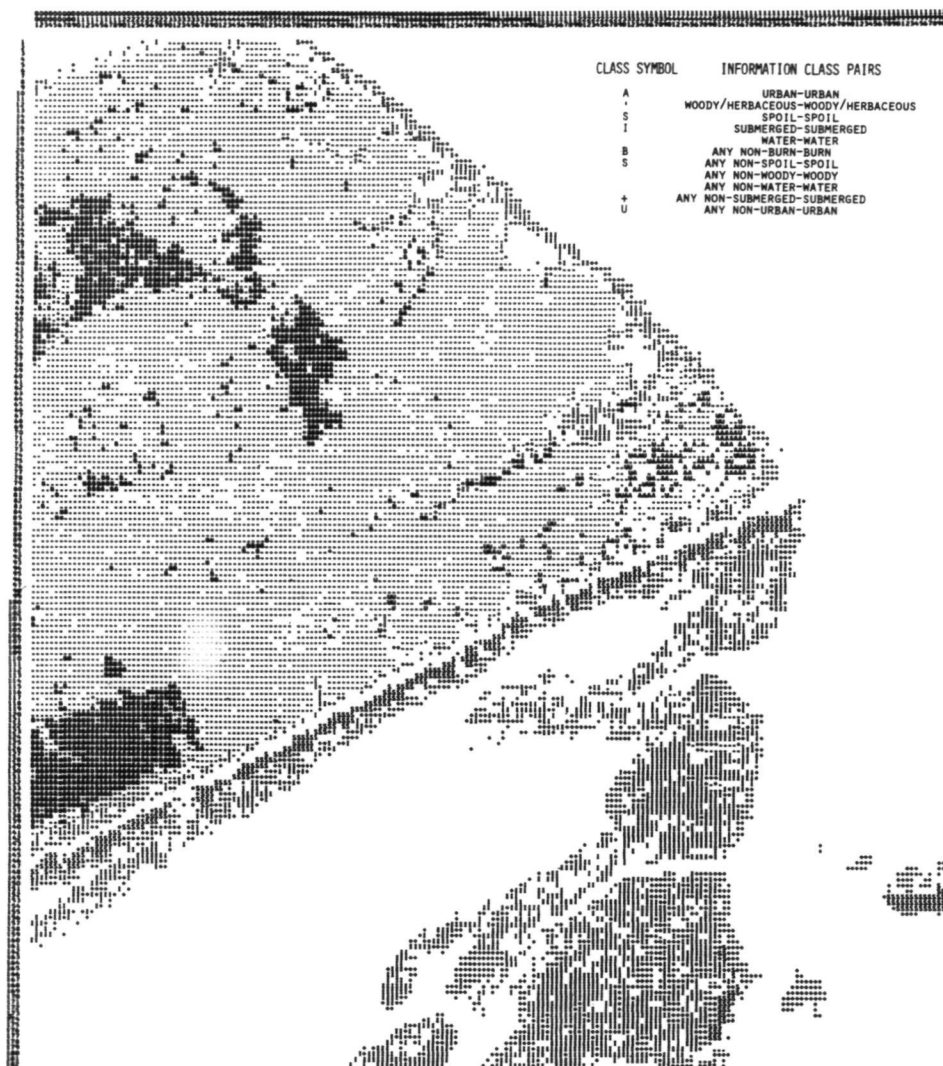


FIGURE 1. RESULTS OF THE POST CLASSIFICATION COMPARISON
CHANGE DETECTION TECHNIQUE FOR THE PORT O'CONNOR
QUADRANGLE.

TABLE I. CLASS PAIRS DEFINED FOR THE POST CLASSIFICATION COMPARISON CHANGE DETECTION TECHNIQUE FOR TWO DATA SETS FOR THE PORT O'CONNOR QUADRANGLE.

Class No.	Informational Classes	
	NOV 72	FEB 75
1	urban---	urban
2	woody/herbaceous---	woody/herbaceous
3	spoil---	spoil
4	submerged---	submerged
5	water---	water
* 6	any non-burn---	burn
* 7	any non-spoil---	spoil
* 8	any non-woody---	woody
* 9	any non-water---	water
*10	any non-submerged---	submerged
*11	any non-urban---	urban
* change classes		

TABLE II. CLASSES DELINEATED BY DELTA DATA CHANGE DETECTION METHOD AND THEIR CORRESPONDING POST CLASSIFICATION COMPARISON INFORMATIONAL CLASSES FOR THE PORT O'CONNOR QUADRANGLE.

Class No.	Informational Classes
* 1	any non-spoil to spoil
* 2	any non-spoil to spoil
* 3	mixed and any non-submerged to submerged
* 4	mixed and any non-urban to urban
* 5	woody to wood and any non-submerged to submerged and any non-urban to urban
6	woody to woody
7	woody to woody and water to water
8	woody to woody
9	water to water
10	water to water
11	water to water
*12	any non-burn to burn
13	water to water
* change classes	

TABLE III. CLASSES DELINEATED BY SPECTRAL/TEMPORAL CHANGE DETECTION METHOD FOR PORT O'CONNOR QUADRANGLE.

Class No.	Informational Classes
*1	Vegetation to soil
*2	Soil to vegetation
*3	Vegetation to burn
4	No change land class
*5	Water to soil
6	No change water class
* change class	

TABLE IV. CLASSES DELINEATED BY LAYERED SPECTRAL/TEMPORAL
CHANGE DETECTION METHOD FOR THE PORT O'CONNOR
QUADRANGLE.

Class No.	Informational Classes	
	NOV 72	FEB 75
* 1	woody	urban
2	urban	urban
3	woody	woody
* 4	urban	woody
* 5	woody	burn
* 6	urban	burn
7	water	water
* 8	spoil	water
* 9	submerged	water
*10	water	spoil
11	spoil	spoil
*12	submerged	spoil
*13	water	submerged
*14	spoil	submerged
15	submerged	submerged
16	water	confusion
17	spoil	confusion
18	submerged	confusion
* change classes		

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APPLICATION OF LANDSAT TO MAPPING INLAND LAKE

WATER QUALITY AND WATERSHED LAND USE

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SUMMARY

Since June of 1974 the Bendix Aerospace Systems Division with consultants from the University of Wisconsin, University of Michigan Biological Station, and Cranbrook Institute of Science have been conducting a LANDSAT follow-on investigation whose objective is to establish the cost benefits of using LANDSAT on an operational basis in the surveillance and control of lake eutrophication. To accomplish this goal, LANDSAT map and data products have been generated by computer techniques to support the Environmental Protection Agency (EPA) modeling study of lake eutrophication in Southern Lake Huron, Saginaw Bay; the State of Michigan's survey of inland lakes and watersheds for the purpose of assessing the effects of watershed land use on lake water quality; and the State of Wisconsin's lake survey to determine eutrophication status, causes, effects, and control treatments.

Inland Lake Water Quality Parameters - LANDSAT data acquired on inland lakes in Michigan and Wisconsin were used to produce color-coded maps showing water in several hundred lakes color-coded to the one acre detail to denote: deep clear water, three categories related to concentration of algal turbidity, water with suspended silt, water with marl turbidity, tannin water, shallow water with rooted vegetation, and shallow water with sand or marl lake bottom. Field evaluations in Wisconsin established the categorization accuracy to be better than 87%. Conventional surveys (surface sampling) by state EPA and US Forest Service in Wisconsin were estimated at costing \$200 to \$1000 per lake. The LANDSAT survey including ground truth and field verification cost less than \$20 per lake thus providing an economical basis for extrapolating water quality parameters from point samples to unsampled areas and provided a synoptic view of the inland lakes and water mass boundaries that no amount of point sampling could provide.

Bendix has tested a number of different approaches to mapping water quality from LANDSAT. The best approach is as follows. (1) Categorize LANDSAT CCTs on MDAS. Use available surface truth (water quality parameter measurements) only as a guide to assure that a wide range of lakes are entered as training sets. (2) Plot spectral curves of each training-set lake (10-15 typically). (3) Compare curves, or transparencies thereof, and group according to shape and relative position (5-7 groups typically). (4) Re-assign colors so that each group of lakes has a different color. (5) Film complete study area. (6) Compare color of all lakes mapped in study area with surface truth and establish color key to relate each water quality parameter to each map color.

Land Use - Five LANDSAT scenes were processed to inventory land cover within 19 watersheds selected by the Michigan DNR as having a representative range of urban development. Maps and data products included; color-coded land cover maps and overlays at scales ranging from 1:24,000 to 1:1,000,000 where the color is used as a code to designate the land cover category. Other data products included computer printouts within the watersheds and digital land cover files. The digital files provide the interpreted land cover information in a geographical grid format for use by computerized resource management systems. Level I land cover categories (Urban, Agricultural, Rangeland, Forest, Water, Wetlands, and Barren) were obtained from all 5 scenes with categorization accuracy of greater than 90 percent. Location accuracy for the map products was about 1.0 pixel (rms). Within one 13 county region (5 LANDSAT scenes) 39 land cover categories were mapped.

Watershed land cover inventories which included color-coded maps and overlays, at various scales, tabular data, and digital cover files were produced from LANDSAT CCTs for a price of 0.1 to 1.0 cents per acre depending upon size of test area and map scales. Similar products produced from any other source would have cost two to ten times more. The land cover data is now being used by the State of Michigan and three state regional planning agencies to develop relationships between categorized land use and lake water quality.

3MIT

EXPERIMENTAL LAND SYSTEMS MAPPING

WITH DIGITAL LANDSAT IMAGES

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ABSTRACT

Terrain mapping with Landsat images usually is done by selecting single types of features, such as soils, vegetation, or rocks, and creating digitally classified maps of each feature. The individual map can then be overlaid or combined to characterize the terrain. Integrated terrain mapping, on the other hand, combines several terrain features into each map unit which, in many cases, is more directly related to methods of land management than the single features alone. Terrain radiance, as measured by the multispectral scanners in Landsat-1 and -2, represents the reflective properties of all terrain features within the scanner's instantaneous field of view and is therefore more correlatable with integrated terrain units than with differentiated ones, such as rocks, soils, and vegetation.

A test of the feasibility of mapping integrated terrain units was conducted in a part of southwestern Queensland, Australia, in cooperation with scientists of the Queensland Department of Primary Industries. The primary purpose was to test the use of digitally classified terrain units for grazing land management. A recently published map of "land systems," (made by aerial photointerpretation and ground surveys) which are integrated terrain units composed of vegetation, soil, and geomorphic features, was used as a basis for comparison with digitally classified Landsat multispectral images. The land systems, in turn, each have a specific grazing capacity for cattle (expressed in beasts per km²) which is determined by sampling and measurement of the biomass and its nutrient quality.

Landsat images, in computer-compatible tape form, were first contrast-stretched to increase their visual interpretability, and then digitally classified by the parallelepiped method into distinct spectral classes to determine their correspondence to the land system classes or to areally smaller, but readily recognizable, "land units."

Many land systems were recognized as distinct spectral classes or as acceptably homogeneous combinations of several spectral classes. Statistical correlation of the digitally classified map and the published map was not possible because the published map showed only land systems while the digitally classified map showed some land units as well as systems.

The correspondence of spectral classes to the integrated terrain units means that the mapping of the units may precede fieldwork and act as a guide to field sampling and detailed terrain unit description as well as giving a measure of the location, area, and extent of each unit.

Extension of this mapping and classification technique to other arid and semi-arid regions of the world may be feasible. A similar experiment is now in progress in the northeastern Mojave Desert in California.

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COMPUTER-AIDED ANALYSIS OF LANDSAT DATA ON SHIFTING CULTIVATION

IN EAST AFRICA: PRELIMINARY RESULTS AND FURTHER CONSIDERATIONS

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Shifting cultivation or swidden agriculture persists as a major system of food production in the tropics and sub-tropics. We report here on a preliminary analysis of swiddening in East Africa and the further considerations for remote sensing via LANDSAT which the special characteristics of swiddening seem to involve. These considerations became apparent during our computer-aided analysis of LANDSAT digital data for West Pokot District, Kenya. The details of this analysis are presented elsewhere (Conant and Cary, 1977); our focus here is on the nature of swidden cultivation and the kinds of ground truth and supporting procedures which seem to us necessary in order to realize more fully the potential of LANDSAT satellites for monitoring this system of food production.

In our preliminary analysis, carried out at the Goddard Institute for Space Studies, we were able to infer that the spectral class defined by the training procedure coincided with the informational class of swiddening as practiced in a small but remote and topographically complex part of West Pokot District. In the course of our research, the following considerations emerged:

1. a multi-stage approach, involving conventional aerial photography, will be necessary initially in any given region to facilitate geo-referencing and determining the spectral characteristics of the small and irregularly-shaped areas typical of swiddening;
2. on-ground observations must be directed at the identification of crop-complexes, differential maturation rates and schedules for harvesting the staple cultigens;
3. since swiddening involves alternation between periods of active cultivation and periods of fallow, and since the two often appear remarkably alike (Geertz, 1963), ground observations must include detailed information on plant cover regeneration in fallow areas;
4. a data management system must be developed which incorporates information from aerial photography, from ground observations and from other sources, along with the LANDSAT data;
5. given the variability inherent in swiddening, as well as that of the environments in which it is so often found, initial monitoring of shifting cultivation will require a time-series of LANDSAT data in order to determine if seasonal differences affect the accuracy of regional analyses;
6. and given the general absence of repetitive and detailed agricultural censuses in the tropics and sub-tropics, especially in remote areas such as those of the East African sahel, aggregate or regional analyses can provide information of immediate and practical use.

These considerations and the special efforts which they involve are worth pursuing since small-scale farming, far from being an anachronism, is increasing in Kenya as population pressures grow (World Bank, 1975). Since the expansion of these activities is in the direction of marginal environments, the application of LANDSAT is important for monitoring the effects of such farming on fragile ecosystems.

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WHEAT YIELD FORECASTS USING LANDSAT DATA*

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ABSTRACT

Many of the considerations of winter wheat yield prediction using Landsat data are discussed. In addition, a simple technique which permits direct early season forecasts of wheat production is described.

1. INTRODUCTION

The accurate forecast of production of agricultural crops, particularly those subject to international trade, is becoming a more urgent requirement due to the growing world population and the resulting food supply problem. Past evidence shows that traditional approaches have sometimes proven inadequate. The purpose of the investigation described here is to determine the extent to which Landsat data can be used to improve winter wheat crop production forecasting capabilities.

The production of an agricultural crop can be thought of as the product of the yield (e.g., bushels/acre) and the area (e.g., acres). Remote sensing data, and Landsat data in particular, can potentially be used to assess both crop yield and crop acreage. In this study we consider first the problem of estimating wheat yield (per acre) using the data known to be from wheat fields. This problem is addressed by demonstrating the nature of yield prediction using Landsat data, by comparing such yield prediction to other methods, and by studying the consistency of Landsat yield relations from one site or acquisition to another. Second, we consider the possibility of estimating total wheat production without a determination of whether each portion of data is from a wheat field. An initial test of a technique designed to make such forecasts using early-season Landsat data is presented.

2. BASIS FOR LANDSAT WHEAT YIELD FORECASTING

The fundamental propositions on which Landsat forecasts of wheat yield are based are that: (1) a good early-season indicator of potential wheat grain yield is the degree of vegetative development; and (2) the degree of wheat vegetative development can be estimated using Landsat data.

Farmers and agronomists have long felt that there is a relationship between degree of vegetative development and yield. In fact, traditional ratings of "stand quality" are based on visual estimates of vegetative cover, measurements of stand height, or similar quantities. It has been recognized that such indicators are especially useful since they incorporate and integrate the effects of important environmental conditions, from meteorological factors such as precipitation and solar radiation, to cultural factors such as fertilization and irrigation. No growth model yet developed has been able to perfectly simulate the synergistic effects of all such variables, but the crop itself, by definition, does so. Until recently, it has been difficult to get precise and timely field observations of crop condition over large areas, so estimates of potential yield based on such observations have not generally been practical. However, the

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advent of earth resource satellites such as Landsat has presented the possibility of monitoring actual crop condition over large areas in a timely fashion.

Returning to the fundamental propositions mentioned above, the question of whether field vegetative condition is a good indicator of yield was examined using ERIM field measurements of percent green wheat cover made so as to characterize entire fields. The measurements of green wheat cover for each field were then compared with the corresponding farmers' reports of actual wheat yield (bu/acre). Such comparisons using ERIM field measurements at a site in Kansas made during two successive years at equivalent phenological stages are indicated in Figure 1. For these data the correlation between green wheat cover and yield is 0.82. This is a statistically significant correlation and tends to support the proposition that vegetative condition is a good indicator of yield.

The hypothesis that Landsat data can be a good indicator of field condition was also investigated. A variety of transformations of Landsat data chosen to be good measures of green development* were compared to ERIM field measurements of percent green wheat cover. Field average values of a Landsat green indicator are compared with field measured average values of percent green wheat cover in Figure 2. It is clear that there is a high degree of correlation ($r = 0.98$).

The most important test, of course, is whether Landsat data is indicative of potential yield. This hypothesis was examined by comparing field mean values of Landsat green indicators with farmers' reports of actual grain yield harvested. An example of this relationship is shown in Figure 3. The correlation between the Landsat green indicator and yield for this example is 0.80. This relationship is statistically significant.

In summary, the fundamental propositions stated earlier in this section seem to be supported by the above evidence. Therefore, we will proceed to examine other aspects of Landsat relationships with yield.

3. RELATIVE UTILITY OF LANDSAT AND ALTERNATIVE SOURCES OF INFORMATION FOR ESTIMATING YIELD

Having established that Landsat data are related to yield, an important question remaining is how yield estimates using Landsat data compare to those generated using alternative sources and types of data.

3.1 METEOROLOGICAL DATA

Meteorological conditions are important determinants of the ultimate yield of agricultural crops, including winter wheat. Historically, meteorological information has been used with some success to roughly estimate yield on a regional average basis. However, there are factors other than meteorological conditions that are also important determinants of yield. In our test sites, which are 5 x 6 miles or smaller, we found that meteorological conditions were relatively constant over each site. For example, 30 rain gauges placed throughout a site measured May rainfall as 3.76 inches, with a standard deviation of only 0.43 inches. On the other hand, the yield on the site varied substantially (21.0 bu/acre to 74.0 bu/acre) from field to field. On another test site the yield varied from 3 bu/acre to 65 bu/acre.

The reasons for such variations in yield are apparently largely related to factors other than weather, such as differences in topography, soil type, planting density, fertilization, cropping practices in a field, and irrigation, none of which are accounted for by yield models based solely on meteorological data.

* e.g., $\sqrt{\frac{MSS7}{MSS5}} = SQ75$; $\sqrt{\frac{MSS7 - MSS5}{MSS7 + MSS5}} + .5 = TVI$; (see Section 4.0)

On the other hand, the differences in crop condition and eventual yield found in the local sites are substantially manifested in Landsat data, as indicated in Section 2. Thus, it appears that Landsat data can better account for local variations in yield than can meteorological data.

3.2 FIELD ESTIMATES OF VEGETATIVE CONDITION AND YIELD

Since we are also interested in the potential usefulness of Landsat data for inputs into existing yield models, we analyzed the ability of Landsat data to estimate wheat vegetative condition relative to an alternate field estimate. For purposes of comparison, we used carefully made ERIM measurements of percent green wheat cover as the correct values. For the two data sets where we have data for essentially all green canopies, the correlations with the ERIM measurements for subjective ASCS (Agricultural Stabilization and Conservation Service) estimates of vegetation cover and Landsat green measures are indicated in Table I.

Based on these two tests, it appears that for yield models that require estimates of degree of crop vegetative development, Landsat data may furnish a better estimate than some subjective estimates made by field personnel using traditional approaches.

We also compared information on yield derived from Landsat data with alternative estimates of yield and stand quality. As shown in Table II, this comparison was made on three sites using subjective stand quality ratings and objective yield estimates, both of which were made by agricultural experts in the field just prior to harvest. These results suggest that Landsat indicators of yield are generally as well correlated with yield as are some alternative traditional field estimates made by agricultural experts, even for Landsat data collected well before the field estimates using alternative methods.*

3.3 CULTURAL FACTORS

Some of the factors that cause field vegetative condition and potential yield to vary in a region of similar meteorological conditions are cultural in nature, i.e., they are factors that can be affected by the individual farmer. Data on many of these variables are potentially available early in the growing season, and hence, could be used for early yield forecasting. The relative importance of some of these factors and the degree to which they can be accounted for by Landsat data are discussed in this section.

For a particular site, we investigated the importance of the factors listed in Table III. An analysis of variance was performed for the above factors by linear regression with wheat yield for the fields for which such data was available. From this analysis, it was possible to determine the percent of variance in yield accounted for separately by each of the factors. However, since high correlations exist between some of the cultural variables, the results cannot be treated as though the variables were independent of each other. The results presented in Table III indicate that individual factors associated with fertilization and irrigation account for most variance in yield.

We have performed similar analyses of cultural and Landsat variables on several sites. As a result of these analyses we have determined that individual cultural factors may account for a high amount of yield variance in one situation and very little in another situation. This is probably at least partially because of differences in the correlation of the individual cultural variables from one situation to another. It is also probably a result of the complex relationships between cultural and environmental factors and crop growth. Since these relationships are not yet fully understood, there is risk in relying on such cultural factors for predicting yield.

*Traditional methods using trained field personnel can certainly be more precise measures of field condition than Landsat data, but the traditional methods are sufficiently time-consuming so that they cannot routinely be made on enough samples to characterize large, variable fields.

In all sites which we have examined, a Landsat green measure was found to account for a large amount of variance in yield. This finding lends support to our expectation that a Landsat green measure will account for the combined effects of the complex factors that influence crop growth, and that a Landsat green measure will, therefore, be a good indicator of potential grain yield in a variety of situations.

3.4 COMBINATIONS OF DATA FOR PREDICTING YIELD

In the previous section we discussed the usefulness of various individual cultural variables for predicting yield. In this section we address the question of predicting yield using data from selected combinations of sources.

Table IV gives the results for one site we have examined. Note that, together, all of the cultural variables (1-6) account for a substantial amount of yield variance (75%). Nevertheless, the Landsat green indicators for the four dates (variables 7-10) for which we have processed Landsat data account for even more variance in individual field yield (87%) than all of the cultural variables. The combination of all Landsat and cultural variables accounts for almost all of the variance in yield (94%).

We previously suggested that field condition as measured by Landsat may account for the integrated effects of the factors governing crop growth and potential yield, including the cultural factors. Cultural factors are mostly accounted for by Landsat data in this site. That is, addition of all six cultural factors to the four dates of Landsat transforms increased the variance accounted for by only 6.3%.

In some situations using Landsat data by itself may be sufficient to predict wheat yield with acceptable accuracy on a regional basis. Consider the standard error of estimates of yield. Using the Landsat green measures from the four dates in the previous example the standard error is 4.8 bu/acre on the above test site. If this performance could be achieved on 100 randomly selected fields, with a normal distribution of yields about the mean, the average yield on the 100 fields could thus be estimated to within ± 0.48 bu/acre, a significant potential accomplishment.

While Landsat data alone may be sufficient to estimate yield in certain situations, some combination of Landsat, meteorological, and ancillary data will probably improve yield prediction performance. In such situations, the appropriate combination of data sources will depend on the cost of obtaining and using such data, compared to the benefits.

4. YIELD PREDICTION EXTENSION

Thus far in this discussion we have confined our analyses to the Landsat relations with yield on a given site and time. In some sense, these analyses indicate the best performance we might achieve on another site with identical conditions. However, other sites will seldom exhibit identical conditions, and attempts to extend a yield prediction relation generally produce results that are not quite as good as those achieved locally.

The need to correct for conditions which differ from one site to another has led to investigation of Landsat data transforms (green measures) which retain the maximum of information about green vegetation and potential yield, and the minimum of other information (noise). In our tests, the green measures tended to measure green cover and yield well (retaining most of the yield information present in the original 4 Landsat bands), and had some effect in reducing variation due to other causes. However, no single green measure was always superior to the others tested.

We carried out tests of extensions of wheat prediction by developing yield-predictive relations on one site and applying them on another. Each relation

was formed using one of the Landsat green measures or using the four Landsat bands. The results of the tests are shown in Table V.

In one test, a Landsat wheat yield relationship developed on May 21 Landsat data was applied to May 20 Landsat data collected on the same site. The May 21/20 test shows that there is only a modest reduction of local yield-predictive information by use of either green measure transform (SQ75, TVI), as evidenced by their slightly larger local RMS error. However, when extending a relationship from one date to another, the non-local (prediction extension) RMS error for individual field yield is less for the transformed data than for the untransformed data. In addition, the mean value of predicted yield is substantially in error using the untransformed four bands of data (5 bu/acre), whereas there is very little bias using the transforms. In other words, the Landsat green measure transforms are better for the extension of yield relations in this test.

In another test, a Landsat wheat yield relationship developed on 18 April Landsat data from one site was applied to 18 April Landsat data from a different site. Again, there is only a small loss of local yield information using either of the transforms. However, both individual field yields and average yield are predicted more accurately by the combination of all four individual non-transformed bands than by either Landsat green measure transformation, as evidenced by the smaller non-local RMS errors and smaller bias.

Additional tests of yield prediction extension have been performed, and they have indicated variable results from one test to another. More testing is being done in an effort to gain more insight into possible sources of error. It may be that procedures that are generally optimum can be discovered only by development of a large base of tests of candidate procedures.

5. DIRECT WHEAT PRODUCTION FORECASTS

Thus far we have discussed only the ability to forecast wheat yield (per acre) using Landsat data. By itself, this information would be valuable as part of a system for forecasting wheat production. However, our work to this point has suggested a method for utilizing the relationship between Landsat data and yield, together with other relationships, to effect direct Landsat forecasts of winter wheat production which may overcome certain troublesome problems in some of the existing approaches.

The existing approaches tend to separate the task of forecasting into two separate subsystems consisting of: (1) wheat acreage determination; and (2) regional average determination of per acre yield. The approach discussed below could make it possible to determine production on a pixel-by-pixel basis, using early-season Landsat data, with a single processing step. Thus, it may become possible to survey large areas such as a state or country much more economically than at present, and achieve more timely information. What follows is a discussion of the rationale of the suggested approach, and a demonstration of its initial implementation.

One of the ideas behind the direct wheat production approach using Landsat data is that an appropriate value of production can be determined for each pixel in the scene, perhaps without even the need to specify whether the pixel is wheat.

We have previously shown that several Landsat transforms are good measures of green vegetative cover, and that cover in turn is strongly related to wheat yield. Given the knowledge of the area covered by a pixel the estimate of yield on a per pixel basis can be directly converted to production. An additional fact is that in winter wheat regions such as Kansas, wheat tends to develop significant green cover sooner than most non-wheat fields and can therefore be easily distinguished. (Wheat classification accuracies of 92 and 94% were achieved on two Kansas sites using only the Landsat SQ75 green measure.)

Thus, if a production-predictive relation (developed on wheat fields) is applied to non-wheat pixels, a very low production indication would be expected, and might be a negligible source of error. If applied to pixels falling on a boundary between wheat and non-wheat, an appropriate intermediate value of green cover, and thus, intermediate average production would be estimated. This intermediate value of production could approximate the total amount of wheat production represented by the pixel, which covers an area only partially planted to wheat. Thus, pixels would tend to contribute only their fair share of the total production estimate.

As a part of this procedure it is necessary to establish the production-predictive relationship on an area where ground truth information is available. * With the relationship established, the present approach is to select a threshold below which no wheat production is assigned to a given pixel. The need for such a threshold is dictated by the fact that, in general, some non-wheat pixels generate Landsat green measures which fall above those of some low production wheat pixels. The threshold value is selected to cause errors of omission and commission to compensate.

As an initial test of the direct production forecast procedure, the above approach was employed using the SQ75 green measure on a portion of the 6 May 1976 Landsat data for Site A. Employing the resulting relationship on all of Site A a production forecast of 42,700 bushels was made. This compared favorably with the actual production of 40,600 bushels for this site, an error of only 5.2%. In addition we applied the same procedure to the same site using 18 April 1976 Landsat data, and to a different site (Site B) using 6 May 1976 Landsat data. The resulting production estimates for these tests are shown in Table VI. Note that the total production estimated for the two May 6 tests was within 1.6 percent of the correct total production, well within LACIE desired accuracy.** Whether the compensating effect of apparently random errors in estimating production would prevail over a larger sample of test sites awaits further investigation.

Preliminary indications based on the three test results give encouragement that the direct wheat production approach using early-season Landsat data is worth pursuing. Many more tests in different situations need to be carried out in order to assess the consistency in performance.

In any event, the approach does address some problems that may exist in present methods. The difficulty in locating field boundaries on Landsat data for determination of wheat acreage is alleviated since all pixels can potentially be included in the proposed new technique. Small or irregularly shaped fields can contribute to the production estimate even if not a single pixel falls completely within the field boundary. Furthermore, large bare areas within wheat fields will be assigned little or no production, thereby giving approximately the correct production, without a decision necessarily having to be made as to whether the area should be assigned to wheat acreage or not. Finally, marginal wheat fields, ones which are not likely to be harvested, will not be included in early-season production forecasts if they fall below the green measure threshold.

Present indications are that these desirable features of the direct wheat production approach are being fulfilled. For example, there were several wheat fields in our Site A test for which no "pure" pixels could be obtained. That

* In an operational environment, several carefully selected sites and data from previous years should satisfy the need for training.

** MacDonald, R. B., F. G. Hall, and R. B. Erb, 1975. "The Large Area Crop Inventory Experiment (LACIE) -- An Assessment After One Year of Operation", Proceedings of Tenth International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, Ann Arbor, Michigan.

is, all pixels covering these fields overlapped the field boundary, or very nearly so. One such field had a farmer-reported production of 1001 bushels and an area of 32.7 acres. Even though not a single pure pixel was present, production of 732 bushels was estimated for this field using the direct production procedure, based just on the pixels whose centers fell within the field boundaries.

In Site B there was a wheat field which was not harvested because the stand was too sparse. Every pixel within that field boundary had a green transform value less than the minimum threshold. Therefore, even though the field was wheat, it did not contribute to the production estimate, which is the desired result in this case since no wheat was produced on this field.

6. CONCLUSIONS

As a result of this study, we draw the following interim conclusions:

1. Landsat data can be effectively used to estimate certain variables which are required in existing yield models (such as LAI or percent cover).
2. Landsat indicators of yield are as highly correlated with individual field yield as are estimates using traditional field sampling methods, even when using Landsat data collected several weeks before the field samples are made.
3. A considerable amount of the variance in individual field yield which is not explainable by meteorological data can be accounted for by Landsat data.
4. In order for Landsat data to be of maximal use in an operational system, improvements in the ability to remove the external effects (particularly atmospheric effects) are required.
5. It may be possible in certain situations to make direct wheat production forecasts using early-season Landsat data.

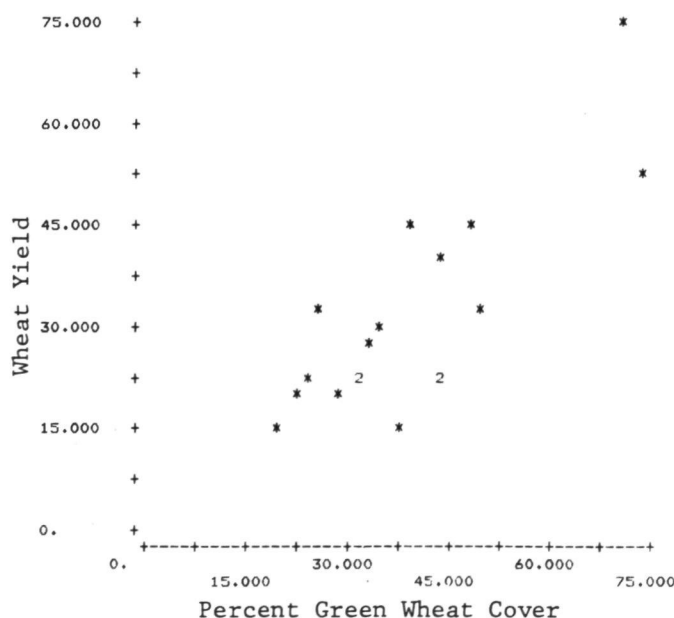


FIGURE 1. ERM MEASUREMENTS OF PERCENT COVER VS WHEAT YIELD
(Combined 1976 and 1975 Data)

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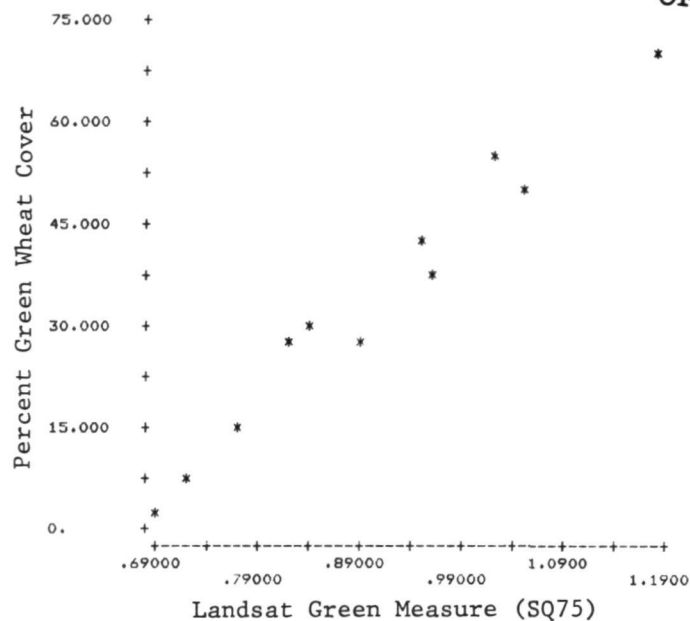


FIGURE 2. LANDSAT GREEN MEASURE VS ERIM MEASUREMENTS
OF PERCENT GREEN WHEAT COVER

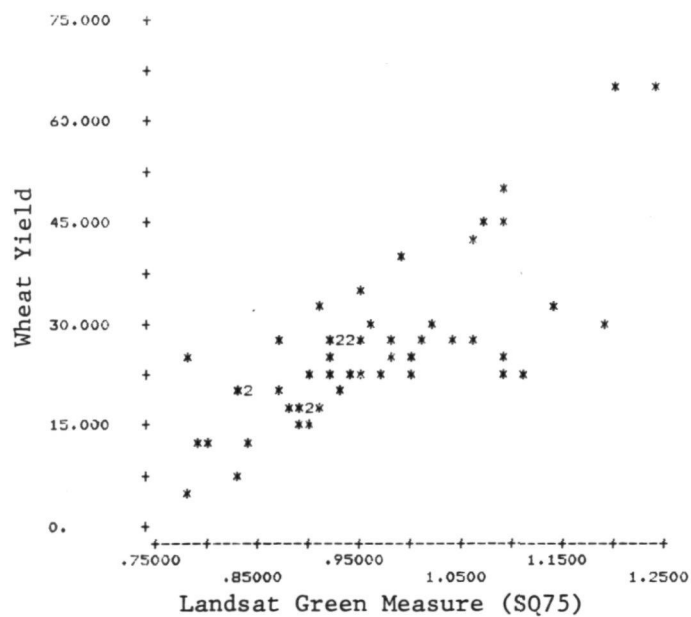


FIGURE 3. LANDSAT GREEN MEASURE VS WHEAT YIELD

TABLE I. CORRELATION OF ERIM MEASUREMENTS OF PERCENT GREEN WHEAT COVER WITH TWO OTHER GREEN COVER MEASURES

	<u>Site A</u>	<u>Site B</u>
ASCS	0.52	0.71
Landsat Green Measure	0.93	0.97

TABLE II. CORRELATIONS OF FARMERS' YIELD WITH FIELD ESTIMATES AND LANDSAT ESTIMATES OF YIELD

<u>Yield Estimator</u>	<u>Site A</u>	<u>Site B</u>	<u>Site C</u>	<u>Average</u>
FCIC*	0.95 ¹	0.26 ¹	0.74 ¹	0.65
Stand Quality**	0.47 ¹	0.78 ¹	0.89 ¹	0.71
Landsat (4 Bands)	0.94 ²	0.80 ⁴	0.79 ³	0.84
Landsat (TVI)	0.93 ²	0.79 ⁴	0.64 ³	0.79

Dates when estimators were available:

¹Pre-harvest (mid-late June); ²15 April; ³21 May; ⁴6 May

*Federal Crop Insurance Corporation objective estimates.

**Agricultural Stabilization and Conservation Service subjective estimates.

TABLE III. PERCENT OF VARIANCE IN YIELD ACCOUNTED FOR SEPARATELY BY SEVERAL CULTURAL FACTORS

<u>Cultural Factors</u>	<u>Percent of Variance</u>
Planting Date	0.1
Wheat Variety	10.6
Fallow Previous Year (yes/no)	35.8
Irrigation (yes/no)	56.3
Fertilization (yes/no)	55.0
Amount Fertilization (lb/acre)	57.4

TABLE IV. PERCENT OF VARIANCE IN YIELD ACCOUNTED FOR BY SEVERAL COMBINATIONS OF CULTURAL AND LANDSAT VARIABLES

<u>Variables</u>	<u>Percent Variance</u>	<u>Standard Error</u>
1-6 (all cultural vars)	74.9	6.89
7-10 (all Landsat vars)	87.3	4.78
4,5,7,10 (optimum four vars)	90.7	4.10
1-10 (all vars)	93.6	3.65

Variable Key:

1 = variety	6 = amount fertilizer
2 = irrigation	7 = SQ75 (May 6)
3 = fertilization	8 = SQ75 (June 2)
4 = planting date	9 = SQ75 (June 12)
5 = cropping	10 = SQ75 (April 18)

TABLE V. TWO TESTS OF EXTENSIONS OF LANDSAT WHEAT YIELD PREDICTION

<u>From</u>	<u>To</u>	<u>Landsat Predictor</u>	<u>RMS Error</u> ¹		<u>Bias</u> ²
			<u>Local</u>	<u>Non-Local</u>	
21 May Site A	20 May Site A	4 Bands	4.40	6.70	-5.00
		SQ75 ³	5.24	5.08	0.00
		TVI ⁴	5.03	4.88	0.02
18 April Site A	18 April Site B	4 Bands	7.41	9.10	-0.23
		SQ75 ³	8.12	10.18	2.15
		TVI ⁴	7.98	9.29	1.17

¹On field by field basis,
in bushels.

²Average difference between actual
and predicted yield, in bushels.

³ $\sqrt{\text{MSS7}/\text{MSS5}}$

⁴ $\sqrt{(\text{MSS7}-\text{MSS5})/(\text{MSS7}+\text{MSS5})+0.5}$

TABLE VI. RESULTS FROM SIMPLE DIRECT WHEAT PRODUCTION ESTIMATION PROCEDURE

<u>Site</u>	<u>Landsat Overpass</u>	<u>True Production</u>	<u>ERIM Estimate</u>	<u>Error (%)</u>
A	6 May 76	40,600 bu	42,700 bu	5.2
A	18 Apr 76	40,600 bu	42,800 bu	5.4
B	6 May 76	27,900 bu	24,700 bu	11.5
A+B	6 May 76	68,500 bu	67,400 bu	1.6

A SOLUTION TO THE PROBLEM OF SAR RANGE CURVATURE

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ABSTRACT

When synthetic aperture radar systems are pushed to attain finer resolution at larger ranges than was previously the case for remote sensing purposes, the geometric signal aberration known as range curvature arises. Known techniques for correcting range curvature are exact at only one selected range, thus forcing neighboring ranges to use the same correction as an approximation. (For Seasat A, four separate correction filters would be required over the design swath width.) This paper outlines a solution to the problem that is exact at all ranges, thus simplifying and improving the image processing for such systems.

1. INTRODUCTION

Synthetic aperture radar systems achieve beam sharpened azimuth resolution by coherently exploiting the incremental changes in range between the sensor and an object as it moves through the beam, as shown in Figure 1. Range curvature arises if the differential range δR that is beneficial becomes larger than (half of) the range resolution p_r , at which time the resulting signal accumulates an aberration that may prevent the desired range resolution from being achieved.

The radar/object range as a function of time is given by

$$R(t) = R_0 + \frac{1}{2} \frac{(Vt)^2}{R_0} \quad (1)$$

using the first two terms of the Taylor series expansion. The second term of Eqn. 1 (the differential range) takes on its maximum value for the largest value of aspect angle θ which we let be θ_M .

$$\text{Max } \delta R = \frac{1}{2} R_0 \theta_M^2 \quad (2)$$

which is linearly increasing with range. Likewise, the achievable azimuth resolution p_a is proportional to θ_M^{-1} , so we see that range curvature is compounded by greater ranges on finer resolution.*

*In the broadside case, $\theta_M = \frac{\lambda}{4\rho_a}$ so that range curvature, which arises if $\text{Max } \delta R > \frac{1}{2} p_r$

imposes the SAR constraint that if

$$R_0 \frac{\lambda^2}{16\rho_a^2} > p_r$$

then range curvature should be corrected.

Previous techniques used to correct for range curvature are given an excellent summary in Leith (1). These techniques have in common a recognition of the range dependence of curvature described by Eqn. 1. However, it turns out that for optical implementations it is more convenient to work either with the range Fourier transform of (the ensemble of the) functions represented by Eqn. 1, or with the two dimensional transform. In these approaches, the (transformed) range data are dispersed and superimposed, thus one has no choice but to choose a correction that is exact at only one range, and to accept the consequential approximation that results for adjacent ranges. Implementation may be elegant, but in effect a compromise.

2. THE SOLUTION

The key to the solution of the range curvature problem rests in recognition of the coordinate system in which the aberration arises within the sensor/object space itself. From Figure 1, the incremental curvature is a single valued function determined by (i) the (instantaneous slant) range to an object, and (ii) its position (with respect to same reference angle) within the real antenna beam in the so-called azimuth coordinate. Operationally, a convenient azimuth position reference is the zero-Doppler line,* and in the simple case modelled here, there is a one-to-one equivalence between angular bearing and Doppler frequency for given object within the antenna pattern at a particular point in time. Indeed, Doppler frequency f_d is given by

$$f_d(t) = \frac{2}{\lambda} \frac{d}{dt} R(t) \quad (3)$$

so that from Eqn. 1 we have

$$f_d(t) = \frac{2V^2t}{\lambda R_0} \quad (4)$$

which relates for each and every object the time history and its Doppler history as it traverses the beam.

The signal history of relevance to the correction problem is to be found in the range image/azimuth Doppler plane. Thus, on reception of SAR data, we require two transformations: range focusing and azimuth frequency (Fourier) transformation. The loci of signals in the (r, f_d) plane is given by Eqn. 1, with a linear change in variables according to Eqn. 4, yielding

$$R(f_d) = R_0 \left[1 + \frac{\lambda}{2V} f_d \right]^2 \quad (5)$$

as plotted in Figure 2.

This apparently trivial step has many ramifications. First, it is conditional on there being sufficient signal structure (large time-bandwidth product) so that the one-one mapping from time to frequency is valid. This is the case for Seasat A, and other SAR devices in the class we are considering. Second, the correction to be accomplished is explicitly represented by the second term of Eqn. 5, which is range and Doppler dependent. Since it is gently quadratic in Doppler and linear in range, it may be realized by optical or digital devices, and is exact at all ranges so compensated. Third, the range/Doppler plane (surprisingly!) does not occur in conventional anamorphic telescopic optical processors normally used for SAR, although there is no fundamental reason forbidding it! Thus, this implementation would require modification of the current methods, although substantially the same optical elements could be employed. Fourth, in the event several sub-images are to be integrated, each

*Note that for the Seasat case the "zero-Doppler line is neither perpendicular to the satellite velocity vector, nor is it a straight line in the slant range plane.

from a different aspect angle within the real antenna beam, implementation of the (r, f_d) range curvature correction as suggested herein automatically brings about the required registration of these multi-look images, thereby solving another problem facing these systems.

3. CONCLUSIONS

Use of the range image/azimuth Doppler plane allows full correction of the SAR range curvature problem, correct at all ranges and in such a way that multi-look images derived from sub-apertures become automatically registered. The approach is realizable either optically or digitally, although analysis shows that for the Seasat case, in which the model is more complex than that shown here, digital methods are more flexible.

The author would like to acknowledge his indebtedness to colleagues from the Canada Centre for Remote Sensing, the Communications Research Centre, and MacDonald, Dettweiler and Associates with whom many probing discussions have taken place on this and related topics.

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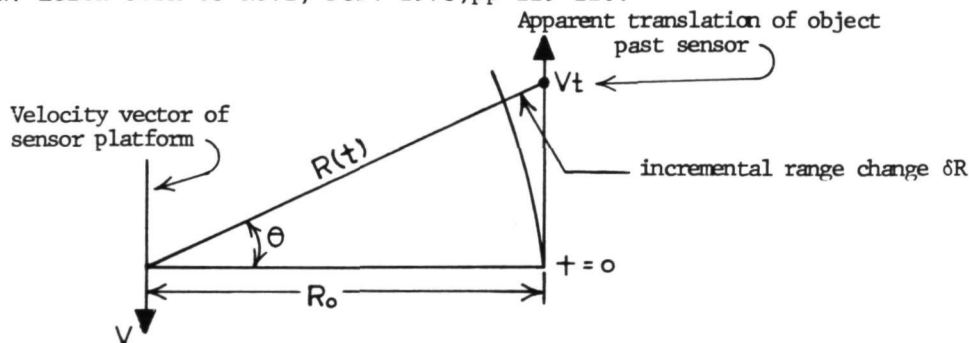


Figure 1. Geometry. Coherent Pulse Ranging System in the sensor/object trajectory plane. $t=0$ at the abeam or $0=0$ position.

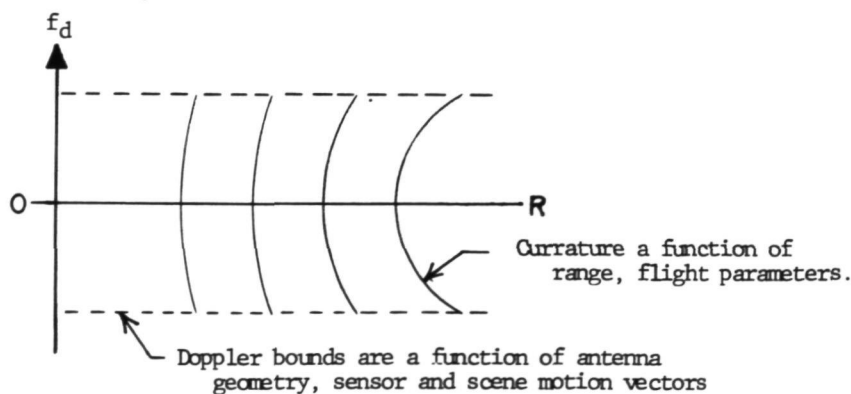


Figure 2. Loci of scatterer range plotted as a function of Doppler frequency shift, for a variety of reference ranges R_0 .

AIRBORNE OCEANOGRAPHIC LIDAR SYSTEM

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ABSTRACT

This paper acquaints the technical community with the characteristics of an Airborne Oceanographic Lidar (AOL) developed for NASA by AERL, Inc. We describe the AOL system, discuss its potential for various measurement applications including bathymetry and fluorosensing, and invite interested investigators to become users.

INTRODUCTION

A major purpose of this paper is to acquaint the technical community with the characteristics of an Airborne Oceanographic Lidar System (AOL) which was developed for NASA by Avco Everett Research Laboratory, Inc. The system has been installed in a NASA Wallops Flight Center C-54 aircraft and is available for environmental measurements by interested users. Accordingly, this paper will discuss the potential of the AOL for various measurement applications and also invite interested investigators to arrange to become users of the AOL.

The AOL is an airborne, spatially scanning, range gated lidar system that can be operated in either of the two modes. In one mode, it can be used to measure topographical relief or water depth (bathymetry) through its range resolution capability (± 0.3 m vertical). Alternately, the system can be used as a fluorosensor to measure fluorescent spectral signatures from 3500 Å to 8000 Å, with 100 Å resolution, of targets which are irradiated by the transmitted laser pulse (e.g. water borne substances), or which passively fluoresce. The system may also be used to measure fluorescence decay times as a function of wavelength. A system description is presented. System measurement parameters are emphasized. These include for both modes as appropriate: ground coverage vs. aircraft altitude, search pattern and sampling density, minimum and maximum depth, horizontal measurement accuracy, excitation spectral range, fluorescence spectral range, spectral resolution and temporal resolution.

Figure 1 is an illustration of the operation of the system in the bathymetric mode. The system detects the laser backscattered return from the water surface and then from the bottom. A typical oscilloscope trace is shown in the figure. By measuring the time interval, between the bottom return and the water surface t_1 - t_2 , the instantaneous depth can be determined. When additional information about the altitude of the aircraft is included, wave height and sea state are also determined. Figure 2 is an illustration of the system operating in the fluorosensing mode. An oil spill is used to represent a typical fluorescing material. In this mode the return is fed into a spectrometer and the characteristic spectrum is recorded. In addition to the spectral channels, there are also several time channels available so that the fluorescent decay vs time can also be monitored. These two parameters can often be used to determine the nature of the fluorescing material. In addition by using the information available from the water Raman return, it is possible to determine the absolute conversion efficiency of the material which can often be a substantial aid in identifying the fluorescent substance.⁽¹⁾

Figure 3 shows a top view and side view of the system as installed in the NASA C-54 aircraft. The system is configured in three levels, all firmly attached to one another for

optical stability. The topmost tier is the transmitter section on which is mounted the laser and an adjustable (2-20 mr) beam expander. Because of the placement of the laser, it is very easy to interchange lasers should this be desirable. The transmitter contains a nitrogen pumped dye laser operating at 400 Hz which enables one to have a wide selection of available wavelengths. If the dye module is removed, the nitrogen laser itself can be used directly, providing a UV output at 3371 Å. If the nitrogen module is filled with neon, this gives a wavelength of 5401 Å, a wavelength very suitable for shallow water bathymetry.

The intermediate tier contains the receiver section which includes a 1220 mm f/4 telescope and a very fast (~ 1.5 nanosecond), sensitive detector for the bathymetric mode. With the insertion of a folding mirror, the system is converted to the fluorosensing mode where the beam is sent to a 40 channel spectrometer, covering the wavelength range from 3500 Å to 8000 Å.

The lowest tier, which is located beneath the aircraft floor in the cargo bay, contains the scanner assembly which consists of a rotating off-axis mirror. Figure 4 shows a typical ground pattern which can be obtained from this type of scanner. Each small circle represents a laser pulse, and the mirror angle and aircraft velocity and altitude are selected to provide an optimum interlace of the laser ground pattern. The aircraft is flying in the positive x direction. Figure 5 shows a view of the system as installed in the aircraft, looking forward. In this view one can see the placement of the electronics racks and the relationship of the scanner to the cargo hatch which already existed in the skin of the aircraft.

Figure 6 is a block diagram of the basic AOL Electronics system. The heart of the system is a 32 K memory Hewlett Packard 2125A computer which both controls the experiment and gathers the data. The data are immediately recorded on a 15 megabyte disc, and subsequently transferred to magnetic tape. This feature allows the system to handle the very large incoming data rate engendered by the 400 Hz maximum operating repetition rate. The data are then available on magnetic tape for post flight analysis. This feature allows the system to have a high area interrogation rate. To the left of the interface, the system consists of high speed state-of-the-art electronics. The 40 channels available can be used either for time or spectral resolution. The interface is standard Camac equipment which translates the output of the high speed electronics into computer language and vice versa. The computer interfaces with a real-time display and can be used to support some real-time processing.

Table 1 is a summary of the optical features of the system, and Table 2 is a summary of the system's electronic features. Table 3 is a listing of the AOL measurement capability and performance characteristics in the bathymetric mode, and Table 4 is a listing of the system's measurement capabilities and performance characteristics in the fluorosensing mode.

Table 5 is a listing of the various applications which have been suggested for the AOL system in the bathymetric mode, and Table 6 is a listing of the various applications which have been suggested for the use of the system in the fluorosensing mode. Suggestions for other possible applications from interested readers would be very welcome. Some additional detailed information on performance requirements, specifications, and design are included in Ref. 2.

Figure 7 is an illustration of the data which were obtained with the system during laboratory tests. In this particular test, a lucite sheet was used to simulate the water surface located at a distance of 25.25 M from the system, and a second target was used to simulate the ocean bottom at a distance of 35.75 M. The peak surface return appeared in channel 4 and the peak bottom in channel 33 giving a ΔR , without signal processing, of 10.8 M. More sophisticated analysis of the data would provide a value closer to the actual 10.5 M.

We have described a remote sensing lidar system mounted on an airborne platform which has the versatility and speed to perform a large number of remote sensing experiments. We expect that it will be a useful tool for the remote sensing community to perform a variety of experiments in order to establish the feasibility of using an airborne lidar to solve remote sensing problems. Interested potential users are invited to contact the authors.

REFERENCES

- (1) R.T.V. Kung and I. Itzkan, Absolute Oil Conversion Efficiency, Appl. Opt. 15, 409-415 (1976).
- (2) NASA Contractor Report CR 141407, "Airborne Oceanographic Lidar System" Final Report Avco Everett Research Laboratory, Inc. (Oct. 1975) Contract Number NAS6-2653.

TABLE 1
SUMMARY OF AOL OPTICAL SYSTEM CHARACTERISTICS/FEATURES

Transmitter

- Laser-Flexible, to provide broad wavelength variability
 - 3371 Å with N₂
 - 5401 Å with Ne
 - 3500-6700 Å with dye module
- PRF variable 0-400 Hz
- Beam Expander - Adjustable 2-20 mr
- Polarizer - Removable and rotatable through 90°
- Folding Mirrors - Kinematic mounting with 3-point adjustments for ease of alignment

Receiver

- Telescope - Externally adjustable baffle (2-20 mr) for daylight S/N optimization
- Field Stop - Electrically adjustable (0-20 mr) for daylight S/N optimization
- Polarizer - Removable and rotatable through 90
- Detector Assembly - Mode changes between bathymetry and fluorosensing
 - achievable thru quick insertion of folding flat
 - Bathymetry: Single, high speed channel
 - Fluorosensing: 40 channel spectrometer (3500-8000 Å);
 - Resolution - 140 Å/Channel; active or passive
- Check Lamp - Allows quick check of PM response prior to data taking
- Filters - Slide mounted for ease of replacement

Scanner

- Scan Angle - Adjustable at 0°, 5°, 10° or 15°
- Rotational Position - Readout accuracy 2.6 min
- Mounting - Fixed to optical platform for alignment stability

TABLE 2
SUMMARY OF AOL ELECTRONICS SYSTEM CHARACTERISTICS/FEATURES

Control and Data Acquisition Subsystem

- Data Acquisition Electronics
 - Contains 48 channels, 41 presently in use
 - Flexible (2.5 - 100 nsec continuously adjustable channel width)
 - Common Electronics used for both bathymetry & fluorosensing
 - Low jitter (< 200 psec)
 - Fast (< 1.5 nsec risetime)
 - Modularly expandable
- Altitude Intervalometer
 - ± 0.3 m altitude accuracy

I/O Controller Subsystem

- Computer
 - Real time disc operating system
 - Performs scheduling, priorities, interrupts; allows operator interaction
 - Flexible software, easily modified for existing experiments or to implement new experiments
 - Good data gathering endurance with 15 MByte disc
 - Bathymetry mode: 3 min per run
 - Fluorosensing mode: 6 min per run
 - Keyboard with printer provides easy operator access & capability for quick-look data dumps

Display

- Provides real-time raw data presentation for system operators

Recorder

- All data recorded in IBM/ANSI compatible digital format for ease in off-board data processing
- Good tape endurance
 - Bathymetry mode: 9 min per tape
 - Fluorosensing mode: 18 min per tape
 - Data taking limited by aircraft endurance

TABLE 3
AOL MEASUREMENT CAPABILITIES & PERFORMANCE CHARACTERISTICS

<u>BATHYMETRY</u>	
Measurement Depth	6 m with $\alpha = 2 \text{ m}^{-1}$; 10 m with $\alpha = 1 \text{ m}^{-1}$
Area Coverage	One data point per 20 m^2 , $\pm 5 \text{ deg}$ from nadir Capability to $\pm 15 \text{ deg}$
Minimum Measurement Depth	0.6 m
Vertical Measurement Accuracy	$\pm 0.3 \text{ m}$
Horizontal Measurement Accuracy	1.07 m RMS ⁽¹⁾
Sea State	Measurement Provided
Transmitter Wavelength	5401 Å (with neon)
Transmitter Bandwidth	$< 1 \text{ Å}$
Transmitter Pulse Width	3 nsec
Transmitter PRF	$\leq 400 \text{ Hz}$
Transmitter Peak Output Power	10 kW
Transmitter Beam Divergence	2-20 mr Variable with beam expander
Receiver Spectral Resolution	$5401 \pm 2 \text{ Å}$
Receiver Field of View	1-20 mr, variable
Receiver Temporal Resolution	2.5 nsec
Polarization	Available for transmitter & receiver
Measurement Altitude	$\leq 600 \text{ m}$
Measurement Velocity	280 km/hr
Measurement Background	Day & night
Ground truth	Interface for footprint camera provided

(1) System contribution. Total accuracy 5 m RMS

TABLE 4
AOL MEASUREMENT CAPABILITIES & PERFORMANCE CHARACTERISTICS

<u>FLUOROSENSING</u>	
Transmitter Wavelength	3371 to 6600 Å, variable
Transmitter Bandwidth	1 Å at 3371 Å, 2 - 10 Å elsewhere ⁽¹⁾
Transmitter Pulse Width	10 nsec at 3371 Å, 2-8 nsec elsewhere
Transmitter PRF	$\leq 100 \text{ pps}$
Transmitter Peak Output Power	100 kW at 3371 Å, 3-30 kW elsewhere
Transmitter Beam Divergence	3-20 mr at 3371 Å, 1-3 mr elsewhere
Receiver Bandwidth	3500-8000 Å (40 channels)
Receiver Spectral Resolution	140 Å/channel over spectral range
Receiver Field of View	1-20 mr, variable
Receiver Temporal Resolution	8-100 nsec, variable
Sea State	Measurement provided
Measurement Altitude	150 m
Measurement Velocity	280 km/hr
Measurement Background	Day & night
Ground Truth	Interface for footprint camera provided

(1) Varies with dye in dye laser module

TABLE 5
POTENTIAL AOL APPLICATIONS
BATHYMETRIC MODE

Bathymetry and Ocean Physics

- Coastal and Channel Charting
 - Quick Check and Reconnaissance
- Sea State Measurement
- Water Transparency and Turbidity Measurement
 - Sediment Concentration
- Solar Glitter vs Sea State Measurement

Fish School Detection and Track

Height Assessment

- Crops
- Forests
- Terrain

TABLE 6
POTENTIAL AOL APPLICATIONS
FLUOROSENSING MODE

Oil Identification

- Crude and Refined Petroleum Products
 - Survey and Surveillance
- Fish Oils

Water Quality

- Pollutant Identification
 - Industrial Effluents
 - Sewage
 - Hazardous Materials
- Algae Detection and Measurement

Water and Tidal Conditions

- Currents and Temperature

Crop Cover and Forest Assessment

- Type Identification
- Health

Geological Exploration

- Resource Discovery and Survey

Other

- Use of Dye Seeding to Support Other Measurements

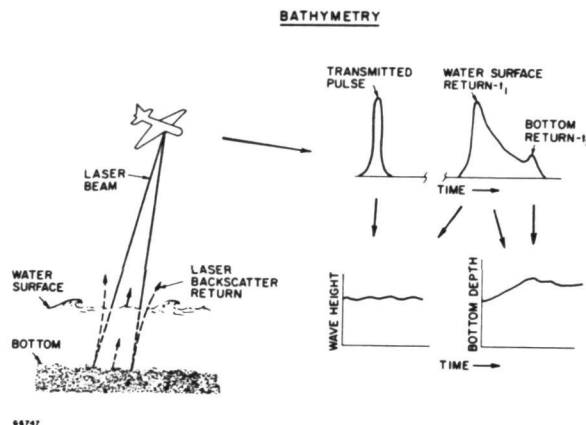


FIGURE 1

SYSTEM OPERATION IN BATHYMETRIC MODE.
Time interval between bottom and surface returns
provides depth information on a per pulse basis.

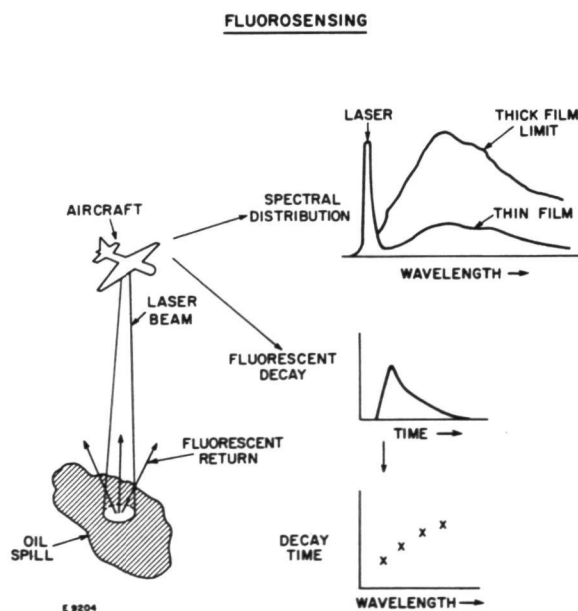
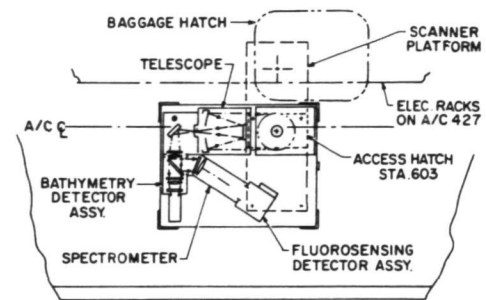
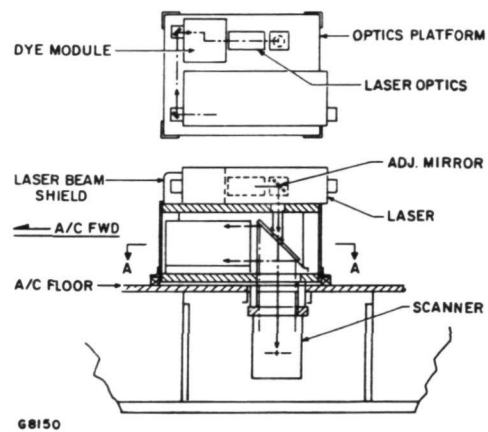


FIGURE 2

SYSTEM OPERATION IN FLUOROSENSING MODE.
Fluorescent spectra and fluorescent decay time vs
wavelength are measured.



SEC A-A

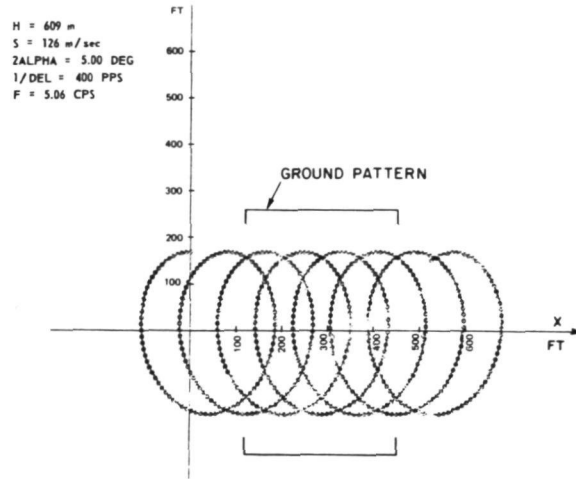


G8150

FIGURE 3

SYSTEM INSTALLATION - Top and Side Views.
The ready accessibility of the dye modules is evident in this figure.

SCANNING PATTERN FOR CONDITIONS SHOWN



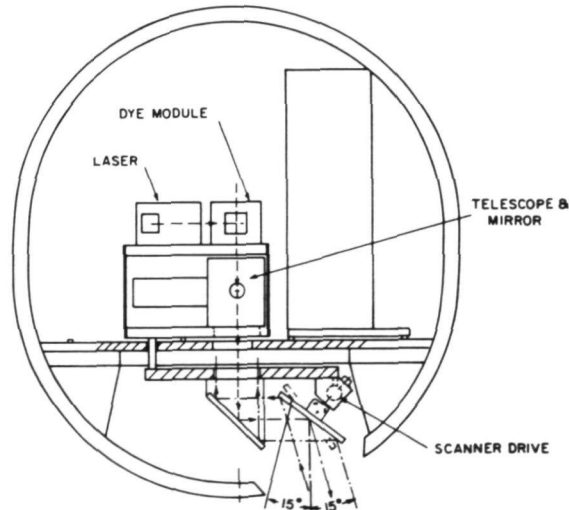
ORIGINAL PAGE IS
OF POOR QUALITY

G8091

FIGURE 4

TYPICAL SCANNING PATTERN

The ground scan pattern can be adjusted to match coverage requirements. The aircraft velocity lies along the x axis.



G8151

VIEW LOOKING FWD

FIGURE 5

SYSTEM INSTALLATION - Forward View.
The scanner configuration in the C-54 cargo hatch is clearly shown.

AOL
BASIC ELECTRONICS SYSTEM BLOCK DIAGRAM

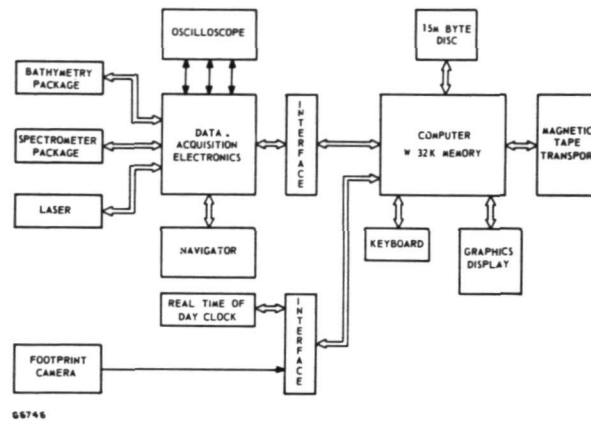


FIGURE 6

AOL ELECTRONICS
The electronics provide for high data rates and large data storage capacity with real-time display for operational ease.

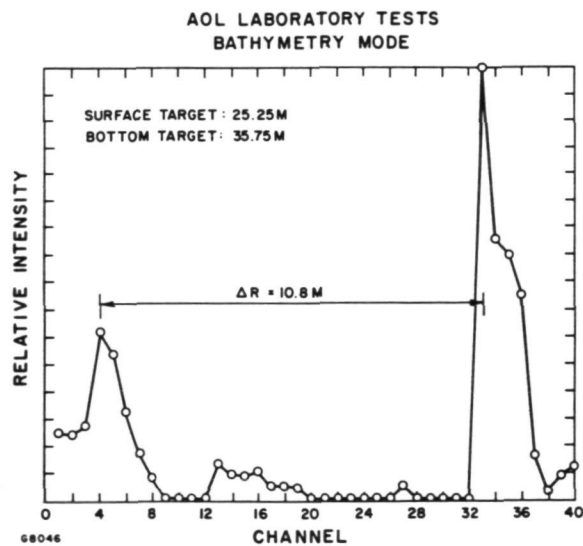


FIGURE 7

AOL LABORATORY DATA BATHYMETRY MODE
Simulated surface and bottom returns are shown.

COMPUTER-AIDED CLASSIFICATION FOR REMOTE SENSING IN AGRICULTURE AND FORESTRY IN NORTHERN ITALY

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ABSTRACT

A set of results concerning the processing and analysis of data from LANDSAT satellite and airborne scanner is presented. The possibility of performing inventories of irrigated crops - rice, planted groves - poplars, and natural forests in the mountains - beeches and chestnuts, is investigated in the Po valley and in an alpine site of Northern Italy. Accuracies around 95% or better, 70% and 60% respectively are achieved by using LANDSAT data and supervised classification.

Discrimination of rice varieties is proved with 8 channels data from airborne scanner, processed after correction of the atmospheric effect due to the scanning angle, with and without linear feature selection of the data. The accuracies achieved range from 65% to more than 80%.

The best results are obtained with the maximum likelihood classifier for normal parameters but rather close results are derived by using a modified version of the weighted euclidian distance between points, with consequent decrease in computing time around a factor 3.

1. INTRODUCTION

Investigation of the possibility of performing selective acreage estimations from LANDSAT satellite data is among the main objectives of the AGRESTE Project [1] sponsored by the European Communities for application of remote sensing to agriculture and forestry. Inventory of given agricultural and forestal species under European conditions requires to consider extensions which are often rather reduced with regard to LANDSAT resolution. This in turn leads to devote much work and care to prepare the ground truth documents, to divide the continuous areas into discrete elements following the scanning grid of the satellite and to compare (overlay) quantitatively the discrete document obtained with the classification results.

The studies presented here, performed with well known classification methods, will rely upon the preceeding considerations. The concept of supervised classification is applied, although an unsupervised clustering technique is introduced in one case as a complementary method.

The first method used, is the so-called "maximum likelihood" scheme (referred to henceforth as M.L.) for class distributions described by normal parameters, where the a priori probability distributions for the classes are assumed to be equal for all classes, which is a reasonable assumption when applying Bayes' inversion rule in a supervised classification context [2]. The vector to be classified is then attributed to the class for which the membership probability is maximum.

The second method used can be considered as formally identical to the M.L. scheme, but with the assumption that all the variance-covariance matrices describing the class distributions are diagonal. From another point of view it can be seen that the method calculates the euclidian distances between any vector to be classified and the mean vectors of the classes of interest, it then weighs the distances by the variance of the classes as in ref. [3]; lastly it constructs the following distance between the vector and class C:

$$\sum_{i=1}^n \frac{d_i^2}{v_i} + \ln \prod_{i=1}^n v_i,$$

where d_i is the euclidian distance for channel i , v_i is the variance for channel i , n is the number of channels (dimensions) and the first term is the weighted euclidian distance used in ref. [3]. The unknown vector is consequently assigned to the class for which the distance just described is minimum. This second method is simpler and much less time-consuming than the M.L. method and will be referred to henceforth as the "modified euclidian distance" (M.E.D.).

As a matter of fact, the AGRESTE Project is actually devoted to the study by remote sensing of three given "targets": rice as a crop present in Southern France and Northern Italy, planted poplar groves in flat areas in the same zones and natural forests (mainly beeches) over mountainous zones covering the frontier between the two

countries. The project is carried out in collaboration with various French and Italian institutes and the results illustrated hereafter deal with typical areas within the Italian test sites studied with the methods just described.

A further objective of the AGRESTE Project regards the feasibility of discrimination between different varieties of the same agricultural crop, particularly discrimination between varieties of rice. Up to now, the only way to reach this objective, even to a limited extent, is to use data from airborne scanners; in fact the reduced dimensions of the controlled rice fields available for this scope and the insufficient spectral resolution of LANDSAT do not allow the use of satellite data for this study at the time being. Results of classification of rice varieties will then be described, using M.E.D. and M.L. schemes, together with linear feature selection by principal components analysis; correction of the variation of the atmospheric effect due to the scan angle will also be introduced following the so-called "long track averaging" procedure applied to the mean and the variance of the data.

2. RICE AREAS

The test site for rice studies is located South-West of Milan in a flat area between the Po river and its tributary, the Ticino. The ground truth was prepared in collaboration with Ente Nazionale Risi, Mortara, starting from catastral maps at the scale 1:6000, updated for rice fields location. The surface of the rice fields was calculated, with a maximum error evaluated to 2%, for the control area displayed in Fig.1, the total acreage of which is about 50 km².

As the rice fields are flooded every year from the beginning of May, the best estimate of rice areas is reached by a simple level slicing on the data of channel 7 (near infrared) of LANDSAT in order to put in evidence the water bodies. This is easily done by starting from an accurate examination of the histogram of channel 7 values for a LANDSAT scene acquired within the month of May. Fig.2 presents the result of such a procedure applied to data from a scene of May 10th, 1973, for the same area as in Fig.1. The rice fields are split up in many fragments, some perhaps only several pixels of LANDSAT size; it was not attempted therefore to grid the control area following the pixels of the satellite, but it is seen that the individual fields are recognized fairly well, although in one case a flooded meadow is obviously confused with rice and in some other cases rice fields, not yet flooded on May 10th, 1973, are not recognized.

By taking these facts into account, one finds that the recognized rice area (39.6% of the total area) compares to the ground truth rice area (40.7% of the total area) with an error less than 3%. Other water bodies, like streams and lakes, will be of course included in the rice inventory by this method, but a further processing of the same area acquired by the satellite after the growth of rice allows these areas to be excluded from the bulk results.

3. PLANTED POPLAR GROVES IN FLAT AREAS

3.1 Ground truth preparation

The ground truth document has been set up by Istituto di Sperimentazione per la Pioppicoltura, Casale Monferrato (I.S.P.), from an infrared aerial coverage, scale 1:10,000, which was done in August 1975, along the Po river at the level of the town Valenza, about 100 km downstream from Turin. The zone has an acreage of about 45 km² and is typical of poplar cultivation in Italy, which is concentrated to about 25% along the Po river and assumes a great importance in the production of wood pulp for paper. An exhaustive conventional photo interpretation of all the poplar groves was then done by research workers of the I.S.P. who were able to group poplar groves into four classes from the points of view of age and percentage of ground coverage [4]:

- groves of one year,
- young groves (age 2 - 3 years) with less than 25% ground coverage,
- intermediate groves (age 4 - 6 years) with 25 - 75% ground coverage,
- adult groves (age 7 years and more) with over 75% ground coverage.

The poplar groves were then reported in two comprehensive classes on the available U.T.M. map, scale 1:25,000:

- class 1 grouping all the young groves with ground coverage up to 25%,
- class 2 grouping intermediate and adult groves with ground coverage over 25%.

The global error at this stage is estimated at 2 - 3% of the groves' acreage.

3.2 Discrete ground truth construction

The reference map so constructed was lastly gridded into discrete elements corresponding to the pixels of LANDSAT and stored on magnetic tape to be compared afterwards with the classification results. The gridding was done by following an iterative process between reference map and classification results in order to ascertain the direction of the satellite scanning on the map and the location of some "one pixel" marks both on map and LANDSAT data. The interpreted areas were then obtained from the corresponding discrete contours (given as input) by running a contour-follower routine. As already specified, the overall accuracy of the above mentioned procedure

is crucial for the reliability of the classification results stated afterwards, on account of the reduced dimensions of the individual areas studied (even one pixel size in extreme cases). It will be seen by comparing Figs.3 and 4 that the accuracy necessary for that scope was achieved. Figs.3 and 4 successive figures are photographs of grey level images from a cathode ray tube unit. Fig.3 represents a discrete ground truth display of the Po river, poplar class 1 and poplar class 2.

3.3 Classification methodology

The general idea was to perform the training of the algorithms in a few limited zones and thus to check, from a rather operative point of view, the effectiveness of the classification methods for the whole control area.

The training sets were determined after a preliminary clustering of the data of the whole area using euclidian distance between points as similarity measure [5], in order to put in evidence suitable clusters of pixels in the sense of uniformity and geographical location. They were then cleaned from marginal or anomalous points in order that they should exhibit unimodal or nearly unimodal distributions. The training sets retained for poplars are seen on Fig.3; they both belong to class 2 mentioned in section 3.1. It was not possible to retain training sets for class 1 because the insufficient ground coverage - owing to the variability of the ground conditions - causes dispersion in the data and hence in the classification results. Training sets were also determined for unidentified but homogeneous clusters outside the poplar groves and for the Po river, so that an exhaustive classification of the area became possible by using one class "poplars", one class "water" and three unlabelled homogeneous classes.

The classification methods utilized were the "maximum likelihood" (M.L.) scheme as developed by Borden et al. [6] and the "modified euclidian distance" scheme (M.E.D.) (see section 1) which were both run without any threshold for the classes.

3.4 Classification results

They are shown in Tables 1 and 2, some of them are displayed in Fig.4. Tables 1 and 2 are the so-called "performance matrices" between ground truth and classification for M.L. and M.E.D. methods. They are computed by comparing the discrete ground truth map and the classification results. They are organized in one row for each ground truth category and give the percentage of pixels well classified into that category and misclassified into the other categories. In the present case the poplar classes 1 and 2 were classified into a single poplar class for the reasons stated in section 3.3.

A study already done, partly over the same zone [7], showed that by merging together three suitable LANDSAT scenes (acquired on June 15th, July 3rd and September 13th, 1975) it was possible to recognize the older poplar groves (class 2) with an accuracy better than 80% and to discard almost completely the younger groves classified within the single poplar class. This discrimination is important on account of the fact that the older class (from 4 years age) contains all the amount of wood available each year for industrial needs.

As an improved procedure was available in the meanwhile for ground truth construction and overlay, a more accurate study was undertaken with the "best" among the three scenes, i.e. June 15th, 1975, in order to see the limits of single scene processing for this problem. The trends of the results are very similar for both M.L. and M.E.D. methods. About two thirds of class 2 poplars are classified as poplars while only a quarter of class 1 is recognized. Misclassifications occur also between poplars and water but this is due almost entirely to the difficulty to separate properly the Po river from the neighbouring poplar groves on the discrete ground truth document (it is recalled that the I.F.O.V. of LANDSAT is about $80 \times 80 \text{ m}^2$). The class labelled "others" collects the three unidentified homogeneous classes referred to in section 3.3.

As a supplementary information, the ratios

$$\frac{\text{number of pixels classed into a given category}}{\text{number of pixels actually present in that category}}$$

are given in percentage for each classed category. The comparison of the two methods shows that the M.L. scheme is somewhat better but with the drawback of much larger computing time (25 s CPU time instead of 10 s for M.E.D., for classifying 9600 four-dimensional vectors into five classes, with an IBM 370/165 computer).

Fig.4 presents the graphic display of some important data of Table 1: the ground truth of the Po river (dark grey), the older poplars class 2, recognized as such (white), the older poplars not recognized (intermediate grey) and the younger poplars class 1 recognized as such (light grey). Other data were not displayed in order to avoid confusion of grey levels on the photograph.

4. NATURAL BEECH FORESTS IN MOUNTAINOUS AREAS

An inventory of natural beech forests in Northern Italy is important because it is thought that beeches could partially substitute poplars for the production of wood pulp. Classification of beeches in mountainous regions and discrimination between beeches and other deciduous trees growing in the same areas, especially chestnut trees, presents however a higher degree of difficulty than does the classification of planted poplar groves. A study was conducted over a typical area, about 90 km², containing differences of level from 800 to 2000 m and ground slopes up to 35%. Beeches, chestnuts, are present at the junction of two valleys (Vallone dell'Arma and Val Demonte) situated approximately 20 km East-South-East of the town Cuneo.

The major part of what has been said in sections 3.1 and 3.2 about the ground truth work remains valid here, apart from the fact that the conventional photo interpretation of beech and chestnut forests, made in collaboration with the Istituto Nazionale Pianta da Legno, Turin, was not exhaustive; about 50% of the area containing mainly forests was indeed not characterized. The ground truth document containing only the characterized zones is seen in Fig.5.

4.1 Classification methodology

The procedure was similar to the one described in section 3.3, but with some differences. Because of the mountainous topography of the site, separate trainings of the classifier were done respectively in sunny and shadowy zones for beeches while a single training was sufficient for chestnuts and meadows. The training sets are seen on Fig.5. On the other hand the clustering approach to define homogeneous unlabelled classes was not successful in this case on account, probably, of the complexity of the ground conditions; as the ground truth was not exhaustive, membership thresholds had to be imposed to the classes. The determination of thresholds for classes is always somewhat arbitrary; in the present case two suitable LANDSAT scenes were available (July 3rd and September 13th, 1975) and the thresholds were fixed empirically in order that the extensions of the various classes were found as close as possible in the two classifications and similarly as close as possible from the ground truth extensions. Only the M.L. method was applied for this problem and the thresholds were defined as a fraction of the maximum membership probability for each class.

4.2 Classification results

They are given as performance matrices in Tables 3 and 4 for the two LANDSAT scenes utilized, respectively July 3rd and September 13th, 1975 and for the zones effectively characterized on the ground truth. It is seen that the discrimination between beeches and chestnuts is rather good, although the two species present in the ground truth are far from being entirely recognized. The last row in the tables has the same meaning as explained in section 3.4. The results are, however, noticeably better with data of July 3rd from both points of view of inventory and discrimination between beeches and chestnuts, due to a more favourable period of vegetation.

Fig.6 displays the classification results for these data. It is seen, as already said, that the ground truth does not cover the whole classified area although the results obtained within the controlled zones can be very likely extrapolated outside, at least as a global trend. The discrimination between beeches and chestnuts is clearly visible and small isolated chestnut woods on the valley floor are also recognized. Fig.7 is a display of three types of data of the performance matrix in Table 6: beeches well classified as beeches (white), beeches not recognized as beeches - i.e. classified as "others" or left unclassified (light-grey), and "others" classified as beeches (dark grey).

5. DISCRIMINATION OF RICE VARIETIES WITH AIRBORNE SCANNER DATA

5.1 Characteristics of the data

The data were acquired on August 7th, 1975, between 9.11 and 10.32 o'clock in the morning by a Bendix M²S scanner at a date on which the various rice varieties should be in the flowering stage, considered to be favourable for the scope of the operation. The technical data of the scanner are reported in Table 5. The data from channels 1, 2 and 10 were not used, however, due to unacceptable level of noise. The resolution of the data at the altitude of 1500 m is 3.8 m. The flight was done in the region referred to in section 2, to the South of the town of Mortara; the strip of data processed here covers a zone approx. 3 km² in acreage where six rice varieties are present, labelled in the following way on the ground truth document (Fig.8):

Gritna is labelled as G, Balilla Grana Grossa as B, Arborio as A, Carnaroli as C, Rocca as RC, Romeo as RO.

The other symbols in Fig.8 correspond to:

Corn for M, wet meadows for MR and other items - no vegetation - for O.

5.2 Ground truth preparation

The work was done in collaboration with Ente Nazionale Risi, Mortara. The final document (Fig.8) was prepared following the procedure described above but in a much easier context owing to the resolution of the data. All the rice fields present in the strip were not characterized from the point of view of rice variety; the black parts of Fig.8 (apart from roads and lanes in the fields), correspond to fields containing unidentified varieties or mixtures of varieties, which often occur in the studied zone. All the black parts of Fig.8, including this time roads and lanes, visible as straight lines, are then considered as uncharacterized areas on the ground truth map. Fig.8 is a composition of grey levels but it was obviously not possible to represent each ground truth class by a given grey level.

5.3 Classification methodology

The classification was this time exhaustive, including also the zones uncharacterized on the ground truth. No membership threshold was applied to any of the classes and no point was therefore left unclassified. The training of the algorithms was done, as above, on little portions of the ground truth classes as seen in Fig.8. Care was taken that the statistical distributions in the training sets be nearly unimodal although training sets of the same ground truth class could present noticeable differences between the respective distributions. Better global results were obtained, however, with the M.L. method by merging together all the sub-distributions of the same class than by processing such "sub-classes" separately. The opposite was true, on the average, with the M.E.D. method, particularly class A and class M were divided respectively into three sub-classes.

5.4 Atmospheric corrections

As the total scan angle of the Bendix M²S scanner is 100°, it is well known that the variation of the thickness of the atmosphere between the scanner and the ground along a scan line has a systematic effect on the data acquired and may then cause a degradation of the classification results. The "long track averaging" procedure used here to correct this effect, assumes that, in absence of the above mentioned atmospheric effect, the mean and variance for each channel along a column of data (i.e. following the flight axis) would have the same value for all the columns (i.e. from edge to edge in the strip of data acquired). The routine set up calculates then in a first step the mean and the variance of the columns from edge to edge of the strip and successively transforms in a second step the data of each column in order that all the columns have the same mean and variance. This procedure is repeated separately for each channel. As a matter of fact, for practical reasons, the columns are grouped five by five, in the first step and the curves describing the variation of column mean and column variance are obtained by an eight-order polynomial fitting. The correction on the variance has proved to be useful to correct what appears as a lack of contrast towards the edges of the strip in a somewhat accurate visualization of the raw data.

5.5 Principal components analysis

A linear feature selection has been proved by principal components analysis, following Borden et al. [6]. In other words, the linear transformation applied to the data is constructed on the criterion of minimum information loss in the sense of the variance of the data. The transformation matrix is formed by a suitable number (depending on the data reduction desired) of eigen vectors of the variance-covariance matrix calculated over the whole area studied. More details cannot be given in a condensed paper on this well known method.

5.6 Outline of the results

The complete results are displayed in Tables 6 to 11, where UC means uncharacterized areas on the ground truth. They will be briefly commented here. The best result was obtained, as expected, with the M.L. method using all the 8 channels available (Table 6). It is seen that the discrimination is on the average very good between rice varieties on the one hand, between rice and other vegetal species on the other hand. The percentage of ground truth classified as such varies from 65 to 83%, apart from variety RO. The feature selection by P.C. analysis from 8 to 5 dimensions affects very little the results (Table 7), but the calculation time is decreased from 29 min. to 18 min. (CPU time - 134320 pixels processed); the fraction of the total variance conserved in the transformation is 99.2%. The raw classification results are displayed on Fig.9 for this last case. It is seen that the ground truth should be modified in order to contain all the roads and lanes actually present, which would probably improve the percentage of well classified pixels on the diagonal of the performance matrices. It is also seen that the uncharacterized rice fields (in black) on the ground truth are mainly classified as mixtures of varieties with the exception of zones where rice was not recognized; it must be said in this respect, that other varieties, not identified on the ground truth, are present in the same region and were not sampled here.

Tables 8 and 9 contain the results obtained with the M.E.D. method. It will be seen from what has been said on the M.E.D. scheme in section 1, that the linear transformation defined by P.C. analysis, but retaining the dimensionality of the space (i.e. 8 dimensions) should improve the results of the method because it has the tendency to decouple the variables as the global variance-covariance matrix of the whole area becomes diagonal. Table 9 presents the results for such a procedure and the comparison with Table 8 is conclusive. The results are not as good as those obtained



with M.L., especially for varieties C and RC, but the calculation time is reduced from 29 min. (or 18 min.) to 5.5 min.

All the results commented up to now were obtained after performing on the data the atmospheric correction described in section 5.4, applied to both mean and variance of the data. Table 10 contains results with M.L. method, 5 dimensions, without atmospheric correction, which compare with Table 7 in a very conclusive way, especially for varieties C, RC and RO located partly or entirely, towards the edge of the data strip. The correction was applied only on the mean for the results displayed in Table 11 and the effect, although limited to second order, is however noticeable by comparing Table 11 to Table 7.

6. CONCLUSIONS

Elements of an answer to some of the questions raised in the framework of the AGRESTE Project have been specified along this study. Acreage estimation of rice-cultivated areas has proven to be possible, from LANDSAT data, with an accuracy better than 95%, when using a scene acquired during the period when the rice fields are flooded. Other studies showed that the accuracy is decreased to 80% when data belonging to the growing season are processed separately.

The recognition of planted poplars in the Po Valley was not exhaustive, as about 70% of the poplar groves suitable for industrial needs are well recognized by a single scene processing but the accuracy increases to 80% or even more when several scenes acquired at different periods are processed together. The inventory of natural beech forests in an alpine site to the South-West of Turin proved to be more difficult although about 60% of the beeches and chestnuts present in the ground truth were recognized and the discrimination between the two species was accurate to about 80%. From a more operative point of view it must be added that in both cases the sampling was done on reduced parts of the studied zones and that the construction and overlay of discrete ground truth documents on the classification maps gave satisfactory results even on areas as reduced as some pixels in size.

Six rice varieties were well recognized in proportions ranging from 65% to more than 80% by using airborne scanner data including a thermal channel, acquired during the flowering period. Correction of the data from the atmospheric effect introduced by the scan angle brings a noticeable improvement in the results, the long track averaging procedure applied to the mean and the variance of the data was found suitable in this respect. The computing time necessary for the last study was reduced by a factor 1.6 when using a linear feature selection determined by principal components analysis.

Lastly, the comparison along the study between the maximum likelihood method and a modified version of a classifier using a weighted euclidian distance, showed that, at the price of some reasonable loss of accuracy, the computing time can be reduced practically by a factor ranging from 2.5 to 3.5.

As a last remark, the authors are conscious of the fact that the reliability of the above results would be increased by studies over larger areas; these studies are under way and will constitute the next step of the AGRESTE Project.

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Results G.T.	Water	Poplars	Others
Water	76.9	4.1	19.1
Poplars class 1	2.5	27.4	70.1
Poplars class 2	0.6	70.4	29.0
Others	4.5	10.7	84.8
Total classed/ total present	125	83.6	104

Table 1 : Poplars performance matrix for M.L. method

Results G.T.	Water	Poplars	Others
Water	78.9	3.9	17.2
Poplars class 1	2.7	24.4	72.9
Poplars class 2	0.6	66.6	32.7
Others	4.9	8.9	86.2
Total classed/ total present	131	75.3	106

Table 2 : Poplars performance matrix for M.E.D. method

Results G.T.	Low veg.	Chest.	Beeches	UC
Low veg.	38.4	8.9	10.5	42.2
Chest.	13.0	56.7	11.7	18.6
Beeches	6.7	15.5	56.3	21.4
UC	35.1	11.6	15.7	37.7
Total classed/ total present	75.2	149	71.5	

Table 3 : Beeches - chestnuts performance matrix for M.L., July 3, 1975. UC: unclassified

Results G.T.	Low veg.	Chest.	Beeches	UC
Low veg.	53.8	8.7	10.2	27.3
Chest.	12.3	50.4	20.8	16.5
Beeches	13.3	21.1	49.3	16.2
UC	23.8	9.3	14.2	52.8
Total classed/ total present	94.6	160	66.2	

Table 4 : Beeches - chestnuts performance matrix for M.L., Sept. 13, 1975. UC: unclassified

Scan angle: 100° Roll-compensation: ±10° Geometric resolution	Channel Nr.	Center (μm)	Width (μm)	Channel Nr.	Center (μm)	Width (μm)
	1	0.410	0.06	7	0.680	0.04
	2	0.465	0.05	8	0.720	0.04
	3	0.515	0.05	9	0.815	0.09
	4	0.560	0.04	10	1.015	0.09
	5	0.600	0.04	11	11.0	6.0
	6	0.640	0.04			

Table 5 : BENDIX M²S scanner technical data

	G	B	A	MR	M	C	RC	RO	O
G	71.4	7.9	9.8	0.0	2.4	0.2	2.5	0.2	5.4
B	2.9	76.4	1.2	0.1	3.1	1.7	0.4	0.3	13.9
A	11.3	1.3	66.8	0.0	3.9	0.2	3.2	0.9	12.3
MR	0.1	0.0	0.4	83.5	2.2	0.0	0.1	0.0	13.8
M	0.2	0.0	0.2	0.1	80.1	0.0	0.1	0.0	19.2
C	0.8	10.3	0.3	0.0	1.0	64.7	14.7	2.5	5.6
RC	0.9	1.3	4.5	0.0	1.3	0.5	78.3	10.2	3.0
RO	0.2	1.7	8.8	0.0	1.2	0.1	26.0	51.2	10.8
O	0.5	1.2	0.1	1.6	2.8	0.1	0.1	0.1	93.5
UC	2.0	12.0	3.4	0.4	13.8	3.6	1.9	0.6	62.3
Tot.cl./ tot.pres.	105	97	83	89	108	68	210	84	

Table 6 : Rice varieties - Performance matrix for M.L. 8 channels

	G	B	A	MR	M	C	RC	RO	O
G	69.1	7.4	11.5	0.0	3.0	0.6	3.1	0.2	5.0
B	2.9	74.4	1.2	0.0	4.4	2.7	0.4	0.3	13.6
A	15.2	1.0	63.7	0.0	6.4	0.2	2.8	0.9	9.7
MR	0.0	0.0	0.5	85.4	3.9	0.0	0.0	0.0	10.1
M	0.3	0.0	0.3	0.2	78.0	0.0	0.1	0.0	21.1
C	1.1	11.7	0.4	0.0	1.2	62.4	14.6	2.8	5.7
RC	2.1	1.3	5.4	0.0	1.3	0.6	76.3	10.3	2.5
RO	0.2	1.5	11.9	0.0	1.2	0.2	27.0	47.9	9.7
O	1.1	1.4	0.4	1.4	5.4	0.2	0.2	0.1	89.7
UC	2.5	11.9	3.6	0.4	17.6	4.0	2.0	0.5	57.4
Tot.cl./ tot.pres.	111	96	82	90	117	67	204	83	

Table 7 : Rice varieties - Performance matrix for M.L. 5 dimensions

	G	B	A	MR	M	C	RC	RO	O
G	46.3	10.3	19.9	0.0	7.0	1.6	10.4	0.0	4.4
B	2.1	73.4	0.7	0.0	2.7	11.6	0.8	0.1	8.6
A	20.8	4.4	55.3	0.2	6.5	0.3	2.5	2.9	7.1
MR	0.1	0.0	0.2	74.3	5.5	0.0	0.0	0.0	20.0
M	1.9	14.8	1.0	0.3	57.7	0.1	0.0	0.0	24.1
C	2.7	28.4	1.2	0.0	1.6	46.4	12.4	0.1	7.1
RC	1.4	9.5	26.6	0.0	1.0	0.6	51.3	8.6	1.0
RO	0.9	20.5	36.4	0.0	0.8	0.3	15.7	24.2	1.2
O	0.5	5.7	0.5	10.5	11.1	0.8	0.3	0.0	70.7
UC	3.0	19.2	3.6	2.1	22.5	5.5	1.1	0.2	42.9
Tot.cl./ tot.pres.	103	132	95	103	103	61	174	45	

Table 8 : Rice varieties - Performance matrix for M.E.D. 8 channels

	G	B	A	MR	M	C	RC	RO	O
G	61.1	6.6	13.0	0.0	3.5	0.1	0.8	0.1	14.9
B	1.9	65.8	0.5	0.0	4.6	1.1	0.3	0.1	25.8
A	13.4	1.8	60.4	0.0	3.9	0.0	2.0	0.4	18.1
MR	0.3	0.0	0.2	68.2	0.7	0.0	0.0	0.0	30.6
M	0.2	3.2	1.9	0.0	69.3	0.0	0.0	0.0	25.4
C	1.4	23.5	0.5	0.0	2.2	43.4	10.9	0.8	17.2
RC	1.5	2.7	20.8	0.0	0.7	0.1	56.7	9.9	7.5
RO	1.1	5.4	26.8	0.0	0.7	0.0	20.1	29.8	16.0
O	0.2	1.8	0.3	0.4	1.6	0.0	0.0	0.0	95.5
UC	2.3	15.1	3.4	0.2	10.5	2.3	0.7	0.3	65.3
Tot.cl./ tot.pres.	98	104	89	70	100	45	150	48	

Table 9 : Rice varieties - Performance matrix for M.E.D. 8 dimensions after P.C. transformation

	G	B	A	MR	M	C	RC	RO	O
G	61.4	6.7	6.8	0.0	4.6	1.4	14.1	0.9	4.0
B	8.7	55.9	1.4	0.0	4.3	18.0	0.4	0.1	11.2
A	6.3	3.5	64.5	0.1	4.1	0.4	6.0	4.5	10.6
MR	0.2	0.6	0.3	87.0	1.7	0.0	0.0	0.0	10.3
M	0.4	2.4	20.0	0.0	72.8	0.0	0.2	0.1	4.1
C	2.6	30.6	3.5	1.1	15.4	29.3	0.6	0.0	16.8
RC	18.6	0.0	3.3	0.0	10.4	3.7	41.6	0.4	22.1
RO	22.6	0.0	25.2	0.0	1.7	0.0	3.7	15.7	31.1
O	7.2	6.0	0.1	2.9	4.4	0.4	0.3	1.0	77.5
UC	2.8	19.7	6.7	0.8	21.1	8.4	2.4	0.7	37.2
Tot.cl./ tot.pres.	134	104	110	108	145	51	102	37	

Table 10 : Rice varieties - Performance matrix for M.L. 5 dimensions without atmospheric corrections

	G	B	A	MR	M	C	RC	RO	O
G	69.9	9.7	9.8	0.0	3.3	1.0	2.2	0.2	3.8
B	4.4	75.2	0.7	0.0	4.8	6.9	0.6	0.4	7.1
A	16.1	2.9	59.7	0.1	7.5	0.3	3.5	4.6	5.4
MR	0.2	0.3	0.3	86.9	2.9	0.0	0.0	0.0	9.4
M	1.0	0.2	0.7	0.2	81.5	0.0	0.1	0.0	16.1
C	1.8	14.0	0.2	0.0	0.9	66.9	12.8	0.3	3.1
RC	3.6	1.5	12.2	0.0	1.0	1.3	68.1	11.7	0.7
RO	1.0	6.1	22.0	0.0	1.9	0.7	36.9	30.0	1.4
O	2.1	3.5	0.3	1.8	6.7	0.7	0.5	0.1	84.3
UC	4.2	18.0	2.8	0.1	17.2	5.1	2.1	1.0	49.5
Tot.cl./ tot.pres.	125	105	81	91	122	76	201	65	

Table 11 : Rice varieties - As in table 10 but atmospheric corrections on the mean only



Fig. 1 : Ground truth for rice (in black). Approx. scale 1:130,000



Fig. 2 : Rice fields (in black) recognized by level slicing on channel 7
May 10th, 1973

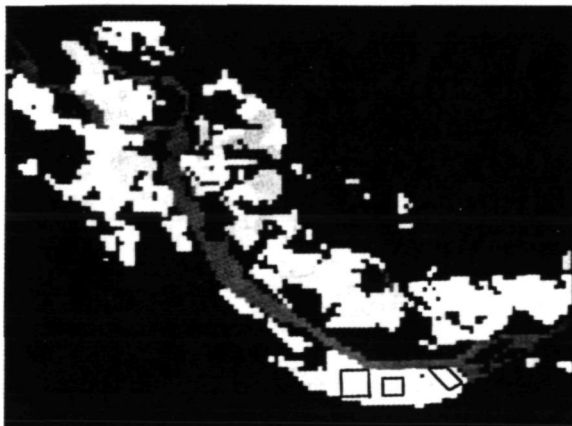


Fig. 3 : Ground truth for poplars. Po river: dark grey; class 1 poplars: light grey;
class 2 poplars: white. Approx. scale 1:120,000

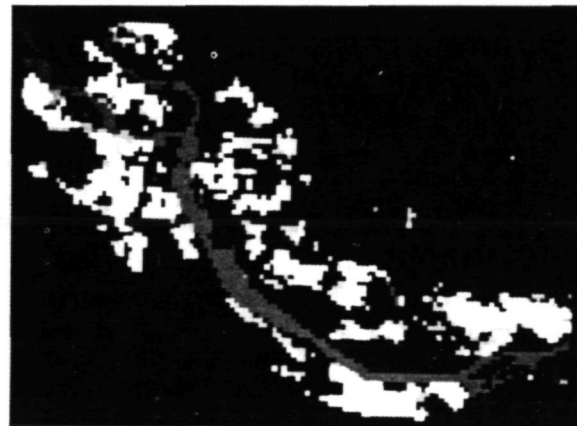


Fig. 4 : Classification results with M.L. Class 2 well recognized: white; class 2
not recognized: intermediate grey; class 1 well recognized: light grey
(very close to white)

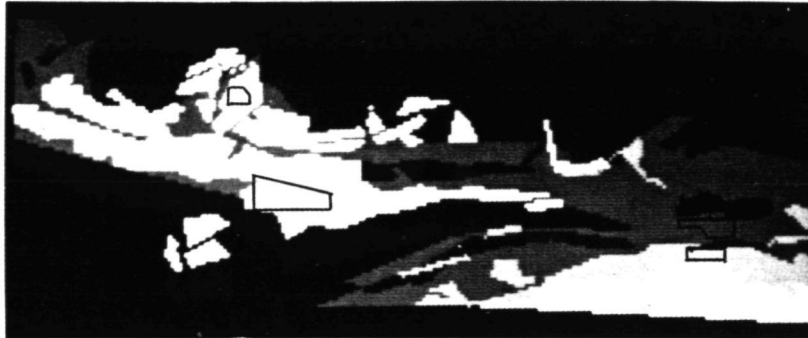


Fig. 5 : Ground truth for beeches and chestnuts. Beeches: white; chestnuts: light grey; meadows: dark grey; uncharacterized zones: black. Approx. scale 1:125,000

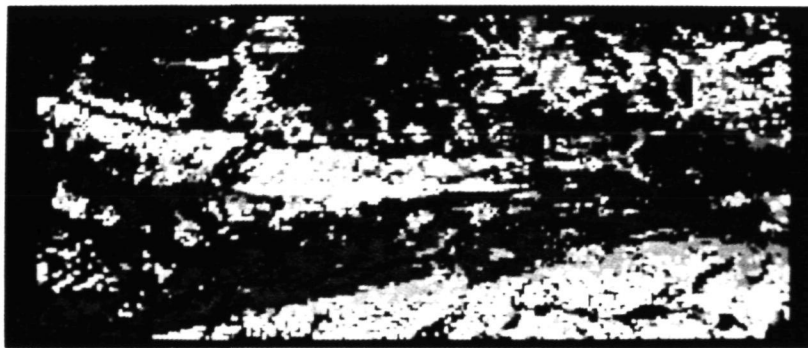


Fig. 6 : Classification results with M.L. July 3rd 1975; grey levels as in Fig.5



Fig. 7 : Detailed results for beeches. Beeches well recognized: white; beeches not recognized: light grey; "others" misclassified as beeches: dark grey

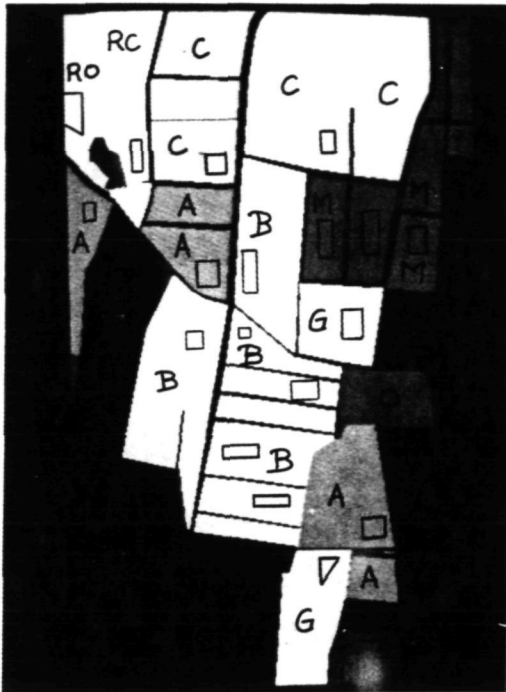


Fig. 8 : Ground truth for rice varieties. G, B, A, C, RC and RO are rice varieties (see section 5.1); MR: wet meadows; O: others. Approx. scale 1:23,000



Fig. 9 : Classification results with M.L. after atmospheric correction and feature selection from 8 to 5 dimensions. Grey levels as in Fig.8

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THE INFLUENCE OF MULTISPECTRAL SCANNER SPATIAL RESOLUTION
ON FOREST FEATURE CLASSIFICATION*

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ABSTRACT

Inappropriate spatial resolution and corresponding data processing techniques may be major causes for non-optimal forest classification results frequently achieved from multispectral scanner (MSS) data. This paper presents the procedures and results of empirical investigations to determine the influence of MSS spatial resolution on the classification of forest features into levels of detail or hierarchies of information that might be appropriate for nationwide forest surveys and detailed in-place inventories. Two somewhat different, but related studies are presented. The first consisted of establishing classification accuracies for several hierarchies of features as spatial resolution was progressively coarsened from (2 meters)² to (64 meters)². The second investigated the capabilities for specialized processing techniques to improve upon the results of conventional processing procedures for both coarse and fine resolution data.

In general, classification performance for forest condition classes improved as spatial resolution was degraded. These results were aggregated to provide a measure of classification performance for more general hierarchies of features that included growth stage, cover type, and physiognomy. Classification performance for these more general hierarchies was substantially higher and also improved as spatial resolution was degraded.

Additional results reported illustrate: 1) the impact of boundary elements and non-homogeneities within forest features on classification accuracy; and 2) the effect of a constant classification rejection threshold for data of varying spatial resolution.

Specialized processing techniques which were investigated included multi-element classification rules for coarse resolution data and a new proportion-space classification technique for fine resolution data. The use of multi-element classification rules for the spatial resolution of (32 meters)² provided improved performance over the results of conventional single-element classification, especially for the most specific hierarchy of forest features. Such rules appear to offer a definite advantage for improving the classification of specifically-defined features with data having spatial resolutions

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comparable to the present Landsat and proposed Thematic Mapper MSS systems.

A proportion-space classification technique showed marked improvement for classifying forest features in data of fine resolution. The technique makes use of classified forest canopy spectral components which may in themselves provide information in support of intensive forest management efforts. Proportions of such components are subsequently used to classify forest features. Application of a proportion-space classification technique to fine resolution MSS data could be utilized in a multistage sampling approach for inventorying forest and rangeland resources.

1. INTRODUCTION

The capability currently exists to acquire and analyze multispectral scanner (MSS) data of forested regions for a wide range of spatial resolutions. Landsat MSS data are among the coarsest in resolution while increasingly finer resolution can be provided by MSS systems mounted in high and low flying aircraft. The forest manager might justifiably ask the question: "which spatial resolution is optimal for classifying features of interest in forest resource surveys?" To help answer the question, one must determine the manner in which spatial resolution affects the classification of forest features. Additional considerations involve the level of information desired and the processing technique employed to provide the information.

Numerous experimental and semi-operational studies have analyzed the discriminability of forest features with MSS data. The vast majority of such studies have utilized data for a single, specific case of spatial resolution that may have been small enough to resolve individual components of forest stands or as large as Landsat resolution. However, the influence of spatial resolution on forest feature classification cannot be readily determined because of inconsistencies in other parameters associated with each study and its respective data set. These parameters might include the objectives of the study, the types of features within the scene, signal-to-noise properties of the data, number and placement of spectral bands, and processing techniques employed.

Two recent studies have shown evidence of improvements in classification accuracy as a result of degrading spatial resolution of MSS data [1,2]. Presented herein are the results of empirical investigations to determine more completely the influence of MSS spatial resolution on the classification of forest features [3,4,5]. Two somewhat different, but related studies are presented: (a) a study of the effect of spatial resolution on forest classification accuracy using a conventional multispectral processing technique and (b) the use of specialized processing techniques to improve upon the results of conventional processing procedures for both coarse and fine resolution data.

2. FOREST CLASSIFICATION ACCURACY AS A FUNCTION OF SPATIAL RESOLUTION

Approach

To provide for a thorough investigation into the effect of MSS spatial resolution on the classification of forest features, we desired data providing common ground area coverage for several cases of spatial resolution that varied from minimum areas small enough to resolve individual components of forest stands to areas large enough to approximate the coarse resolution of the present Landsat systems. To hold other variables constant (e.g., temporal variations, etc.) we degraded a single aircraft data set of inherent (2 meters)² resolution in successive steps to simulate 5 additional data sets having (4)², (8)², (16)², (32)², and (64 meters)² spatial resolutions.

To degrade resolution as realistically as possible, we implemented an algorithm that utilized typical MSS optics and electronics properties in the form of two spatial weighting functions [3]. Each weighting function was low pass filtered and truncated to span five successive resolution elements in directions along the scanline and along the flightline

respectively. When quantized into five intervals and combined into an X-Y matrix, the two weighting functions created an array that, when successively centered on every other element in every other scanline and when multiplied and summed over the surrounding 5 by 5 group of pixels to generate a replacing pixel value, yielded a new data set having one-fourth the number of resolution elements per unit ground area (Figure 1). System noise inherent to the original data was preserved in the simulated data by inserting a quantity of randomly generated high-frequency noise sufficient to compensate for the calculated amount of noise reduction caused by the averaging effect of the spatial weighting array. Application of the spatial weighting array and noise insertion procedure to each successive data set in turn enabled the creation of additional data sets having twice the linear spatial resolution of the preceding set.

The MSS data set included 11 spectral channels collected by a Bendix Modular Multispectral Scanner (M²S) from an altitude of 610 meters (2000 feet). The data were collected as part of NASA Mission No. 290 on 20 November 1974 over the Conroe Unit of the Sam Houston National Forest in east Texas. Data including approximately one million resolution elements, and providing ground area coverage illustrated in Figure 2, were successively degraded in resolution. Forest features were identified according to existing U.S. Forest Service timber stand maps. These features are listed as condition classes in Table 1.

All data sets of varying resolution were processed with a conventional supervised classification procedure that utilized signatures extracted from training sets inside each forest feature. Signatures for these features were extracted anew for each data set from training sets that covered equivalent ground areas in each case of spatial resolution. The ERIM linear decision rule was used to classify all resolution elements on an element by element basis into the respective signature distribution or an unclassified category. Results were tallied to provide the percent correct classification achieved within each feature. The percent of all resolution elements correctly classified in the data set was calculated to provide an overall classification accuracy for the hierarchy.

Classification performance for the hierarchy of condition classes represents the most detailed level of classification for this study. The classification results were aggregated to provide a measure of classification performance for features of more general hierarchies (Table 1). Condition classes were combined into cover types on the basis of species (pine regeneration was retained as a separate feature), and alternately, into features based on maturity that we called growth stages. For the most general hierarchy, all pine saw-timber features were combined into a single physiognomic class to be compared with pine regeneration.

The large range of view angles inherent to aircraft scanner data can result in signal variations caused by large changes in atmospheric path length and terrain bidirectional reflectance phenomena [6,7]. Analysis of scan angle variations in this data set indicated a reasonable degree of independence from such variations for the region of data located 30° either side of the flightline nadir. Thus, we confined the location of training sets and the determination of classification performance to this region.

Results

Figure 3 illustrates the overall classification accuracies that were achieved for the hierarchies of features classified. These accuracies represent the results achieved for training sets from which the signatures had been extracted. By showing classification performance for training sets, we represent an upper limit of performance that assumes each feature area is adequately described by its respective signature(s). Thus, the results are uncomplicated by the additional confusion to the classification performance that may be introduced by unaccounted for nonuniformities within nontraining portions of the features and by boundary elements. (Such confusion existed despite the relatively large proportions of feature areas designated as training sets.)

Classification performance for all hierarchies of features improved as spatial resolution was degraded. Additionally, classification accuracy was substantially higher for hierarchies of less specifically defined features. In other words, improvement in performance occurred as a result of aggregating the classification results of specific features into more general features. For each general feature, previous misclassifications of resolution elements among its specific features were properly counted as correct classification, reducing the total amount of misclassified elements for the respective hierarchy. Thus, the overall accuracy for classifying the physiognomic hierarchy of forest features is higher than for hierarchies of more specific classes — a not-surprising result.

The improvement in performance with degraded spatial resolution resulted from a reduction in scene variation that is inherent in the averaging of information over larger ground areas. This result is best illustrated in Figures 4 and 5 where, for two dimensions, the signature distributions for features are shown at resolutions of $(2)^2$ and $(32 \text{ meters})^2$, respectively. [In tests of spectral channel performance, the two spectral channels illustrated in these figures, namely the red (.65-.69 μm) and near-infrared (.95-1.03 μm) regions, had proven to be among the best for separating the features.]

At $(2 \text{ meters})^2$, the largely overlapping signature distributions obviously offered the least likelihood for successful discrimination of features. The large variance for each signature provides evidence of the spectral non-homogeneity within the training areas, and the small mean separation among the signatures indicates many similarities among the data values of resolution elements in all training areas. Thus, misclassifications of those elements by the resulting signature set will be high. As resolution was degraded, the variance of each signature became smaller while the means for the most part remained unchanged, causing the amount of statistical overlap (competition) among the signatures to decrease. Thus resolution elements in coarser resolution data should have higher probabilities of being correctly classified.¹

Classification performance decreased somewhat when accuracies were computed over the entire area of each feature. Such decreased performance is attributable to greater percentages of misclassified and unclassified resolution elements and can be caused by the increased variance in data values, not completely represented by the feature training set, that results from non-uniformities over the entire feature and the effect of boundary elements around the perimeter of each feature. Figure 6 compares the overall classification performance for training sets to the lower performance achieved for total feature areas with and without boundary elements. In general, the decrease in classification performance for feature areas without associated boundary elements becomes greater in coarser resolution data, possibly suggesting the need for more careful training in coarse resolution data. The impact of included boundary elements serves to further reduce classification performance as spatial resolution degrades, owing to the increased ratio of boundary elements to total feature elements.

Classification performance as a function of spatial resolution was found to be subject to influence by the rejection threshold used in classifying the data. The rejection threshold represents a selected exponent value of the multivariate normal density function of each signature which determines the limits of decision space occupied by the respective signature. Resolution elements having classification exponent values greater than the rejection threshold of the signatures will be unclassified by the decision rule. Results of using a conventional classification approach showed that the use of a constant rejection threshold for all cases of spatial resolution caused a great increase in the percentage of unclassified resolution elements in very coarse resolution data (Figure 7). Presumably, an increased percentage of unclassified resolution elements occurs in coarser resolution data when the rejection threshold remains constant because a relatively smaller total decision space is represented by the decreasing sizes of the signature distributions. Large proportions of unclassified elements will obviously detract from the results of the classification effort and, if considered to be errors, can cause a significant decrease in classification performance for coarse resolution data. Judicious selection of thresholds can reduce the amount of such unclassified resolution elements. Thresholds used to generate the results in Figures 3 and 6 were varied as a function of spatial resolution to maintain a constant small proportion of unclassified elements.

3. USE OF SPECIALIZED PROCESSING TECHNIQUES

Conventional multispectral classification rules are based on information from one resolution element at a time. The previous application of one such rule showed improved classification performance for coarser cases of spatial resolution — apparently due to the reduced variation within the scene that occurs by averaging information over larger ground areas. Obviously,

¹When resolution was coarsened to $(64 \text{ meters})^2$, an insufficient number of resolution elements prevented computing a valid signature for the Immature Loblolly Pine feature. Thus, the abrupt increase in classification accuracies that occurs from $(32 \text{ meters})^2$ to $(64 \text{ meters})^2$ in Figure 3 is due in part to the absence of a competing signature during the classification of the data, again causing resolution elements to have high probabilities of correct classification.

there will be a limit to which data spatial resolution can be coarsened and still be useful for providing other aspects of scene information such as locational accuracy or accurate area measurement capabilities. Additionally, the presence of large signal variations in fine resolution data provides detailed information not available in coarse resolution data.

Technique for Coarse Resolution Data

Multi-element rules use information from groups of resolution elements when classifying a specific element. The so-called "nine-point" rules developed at ERIM [8] determine the classification of a resolution element on the basis of information from that element and its eight immediate neighbors. Such use of proximity information attempts to improve classification performance by incorporating the likelihood that a resolution element represents the same scene class as its neighbors. The influence of neighboring elements can be varied with the selection of a particular rule. Multi-element rules thus offer the potential for providing the improved classification performance of coarser spatial resolutions without the loss of other scene information that occurs with coarser resolutions.

Four multi-element decision rules (known as BAYES9, PRIOR9, PREF9, and VOTE9) were used to classify the (32 meters)² resolution case. All four multi-element rules showed improved performance over the classification results achieved with the single-element rule for (32 meters)² data. For the most detailed hierarchy of features (condition classes), classification accuracies ranged from 13 to 25 percent better (Figure 8). Three of the rules consistently showed performances that were higher than the single-element classification results achieved for (64 meters)² data. Thus, it appears that judicious selection of a nine-point rule can offer improved classification performance that is greater than an improvement that might be realized with standard classification procedures used on coarser resolution data.

Of the four multi-element rules, classification results were always highest for PREF9. This rule uses as its decision criterion the average, over nine elements, of the posterior probability of a feature at each resolution element. Comparison of these results with the results of the single element rules indicates that the increase in accuracy is largest for the hierarchy of condition classes with lesser increases in performance noted for hierarchies of more general features. This trend suggests that when classification accuracy is low using standard techniques, then specialized processing techniques give more improved accuracy than when accuracy is high with standard techniques. Thus, multi-element rules appear to be advantageous for improving the classification of detailed features that may be required in some forest surveys.

Technique for Fine Resolution Data

Poor classification performance achieved with the application of a conventional processing technique to fine resolution data was attributed to the large, overlapping variances of the signatures (Figure 4). These large variances were caused by the wide range of spectral variation within each feature area that resulted from individual resolution elements falling entirely within various spectral classes of forest canopy components such as illuminated pine tree crowns, hardwood tree crowns, illuminated and shadowed understory, etc. The great overlap of signature distributions was caused by the fact that each spectral class of canopy component occurred within several feature areas.

The proportion-space classification technique which we developed and implemented on the fine resolution (2 meters)² data entailed a two-stage procedure that ultimately discriminates features on the basis of average proportions of classified component spectral classes that occur within feature areas. The first stage of the procedure utilized the large variance in the data to classify resolution elements into their respective component spectral class, regardless of feature area. Signatures for the conspicuous component spectral classes in each feature area were defined with the aid of large-scale color-infrared photographs and a zoom transfer scope. Subsequent analysis indicated little capability for reliably discriminating between similar types of component spectral classes from feature to feature. Therefore, we combined such signatures and assessed discriminability for the resultant eight signatures representing different spectral classes of canopy components. Table 2 indicates relatively high classification performances for this set of signatures when used to classify a selected set of resolution elements in all feature areas.

Use of the eight component signatures for classifying representative regions of data within each feature revealed expected differences in the proportions of resolution elements that were classified into the various component spectral classes. Figure 9 illustrates the proportions for the regions of data classified within each feature. (Note that two separate data regions

were classified within pine regeneration in order to observe the extremes of tree density that existed within the feature.) We had anticipated that differences in component proportions from feature to feature would exist, such as manifested in Figure 9, and that the classified proportions of component spectral classes within each feature could possibly provide a means for discriminating among features.

The second stage of the procedure was implemented by partitioning each representative data region into cells of $1000 (2m)^2$ resolution elements (each cell measuring 50M by 80M ground coverage). For each cell, we established a new data vector giving the proportions of previously classified component spectral classes. Thus, a new "proportion space" was defined for describing the cells. These data vectors were averaged together to compute signatures defining component proportions in each feature. Finally, the proportion signatures were used to classify each 1000-element cell in proportion space. Figure 10 illustrates the greatly improved performance achieved for the proportion-space technique as compared to the conventional classification performance previously achieved with fine resolution data.

The procedure described here demonstrates the potential utility of fine resolution MSS data for forest resource surveys. The capability to classify such data into various spectral classes of forest canopy components can in itself provide information to support intensive forest management efforts. For example, proportions of classified canopy components enable the determination of crown closure for various tree crown spectral classes that may influence management decisions affecting silvicultural or pest control operations. Additionally, the application of the proportion-space classification technique can provide accurate forest feature discrimination at a more general level. Such capabilities could be advantageous in multistage sampling surveys of forestry and rangeland resources.

4. CONCLUSIONS

Use of a supervised multispectral data classification approach which incorporated a standard single-element linear decision rule resulted in improved overall classification performance for several hierarchies of forest features in six MSS data sets that ranged in spatial resolution from $(2 \text{ meters})^2$ to $(64 \text{ meters})^2$. Improvement was attributed to a reduction in the number of misclassified resolution elements that occurred as a result of reduced competition among signature distributions. Reduced competition presumably resulted from a reduction in scene variance that is inherent in the averaging of information over larger ground areas.

As expected, improvements in classification performance were noted for hierarchies of more general (aggregated) forest features. Such consistently better classification of more general levels of detail illustrates why higher levels of accuracy can be expected for large-area reconnaissance surveys dealing with generally-defined features than for detailed inventories of specifically-defined features.

Specialized processing techniques applied to both coarse and fine resolution data were shown to offer great potential for improved forest feature classification. Multi-element rules demonstrated the apparent capability for providing the improved classification performance of coarser spatial resolutions without the loss of other scene information that occurs in coarser resolutions. Such rules appear to offer a definite advantage for improving the classification of specifically-defined features with data having spatial resolutions comparable to the present Landsat and proposed Thematic Mapper MSS systems.

A proportion-space classification technique showed marked improvement for classifying forest features in data of fine resolution. The technique makes use of proportions of classified forest canopy components which may in themselves provide information in support of intensive forest management efforts. Application of a proportion-space classification technique to fine resolution MSS data could be utilized in a multistage sampling approach for inventorying forest and rangeland resources.

Results presented here have shown that the accuracy for classifying forest features with MSS data is greatly dependent on the spatial resolution of the data, the level of detail desired, and the processing technique employed. Consideration of these parameters for specific situations can begin to serve as guidelines that will enable forest managers to select the proper data acquisition and processing procedure to get the desired results.

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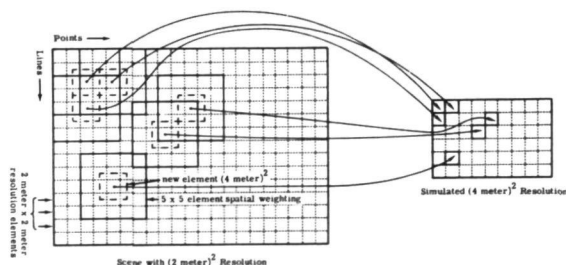


FIGURE 1. ILLUSTRATION OF TECHNIQUE FOR SIMULATED DOUBLING OF LINEAR SPATIAL RESOLUTION



FIGURE 2. FOREST FEATURES IN MSS DATA, CONROE UNIT, SAM HOUSTON NATIONAL FOREST

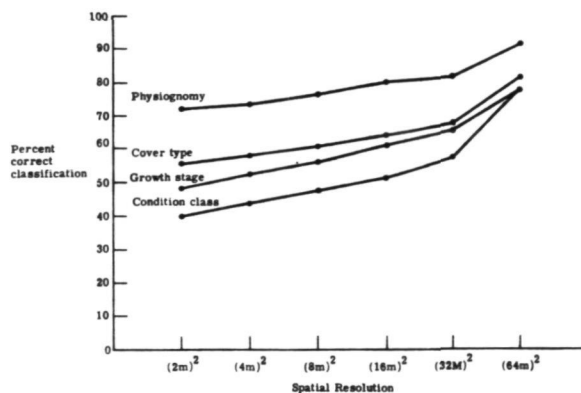


FIGURE 3. CLASSIFICATION ACCURACIES FOR HIERARCHIES OF FORESTRY FEATURES GENERALLY IMPROVE WITH COARSER SPATIAL RESOLUTION WHEN CONVENTIONAL TECHNIQUES ARE UTILIZED

TABLE 1. HIERARCHIES OF FORESTRY FEATURES FOR WHICH CLASSIFICATION PERFORMANCE WAS DETERMINED IN THE SAM HOUSTON NATIONAL FOREST (TEXAS)

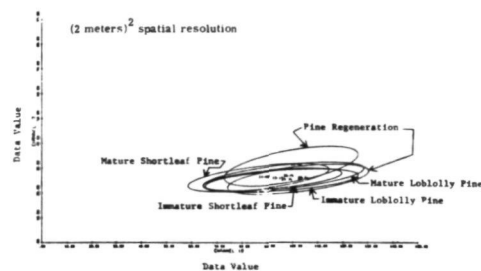
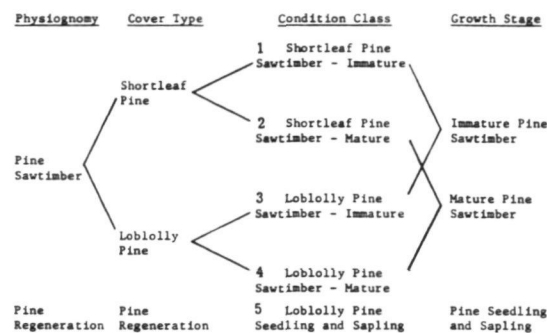


FIGURE 4. SIGNATURE DISTRIBUTIONS FOR CONDITION CLASS FEATURES IN (2 METERS)² RESOLUTION DATA

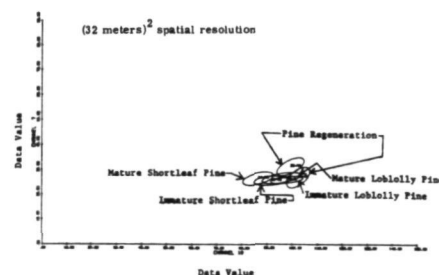


FIGURE 5. SIGNATURE DISTRIBUTIONS FOR CONDITION CLASS FEATURES IN (32 METERS)² RESOLUTION DATA

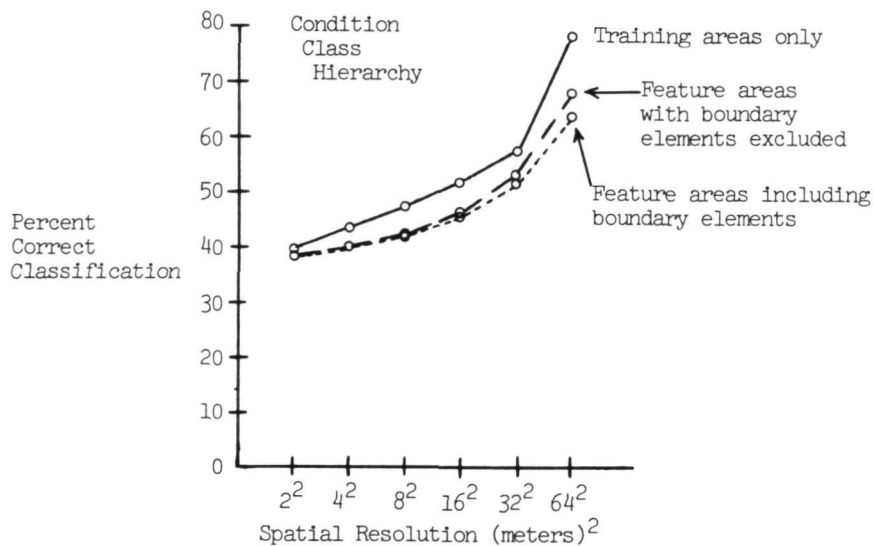


FIGURE 6. COMPARISON OF CLASSIFICATION PERFORMANCE FOR TRAINING SETS WITH THAT OBTAINED FOR TOTAL FEATURE AREAS

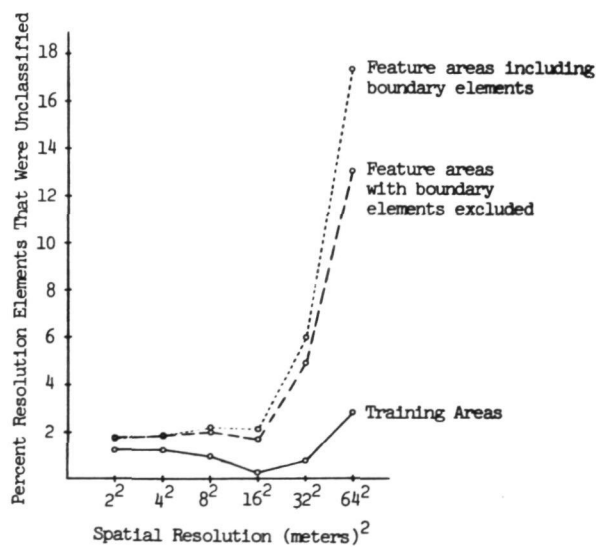


FIGURE 7. EFFECT OF SPATIAL RESOLUTION ON PERCENT OF RESOLUTION ELEMENTS WHICH WERE UNCLASSIFIED WITH A CLASSIFICATION REJECTION THRESHOLD HELD CONSTANT AT THE .001 LEVEL OF SIGNIFICANCE

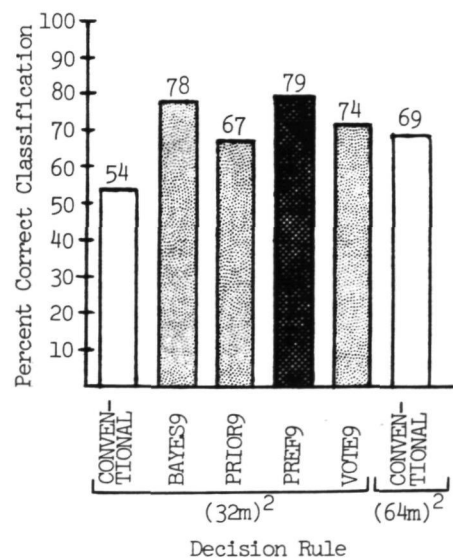


FIGURE 8. COMPARISON OF OVERALL CLASSIFICATION PERFORMANCES ACHIEVED FOR THE CONDITION CLASS HIERARCHY OF FEATURES. Results are for total feature areas with boundary elements excluded.

TABLE 2. RESULTS OF CLASSIFYING SELECTED RESOLUTION ELEMENTS IN ALL FEATURE AREAS

Component Spectral Class		Percent Correct
Illuminated Pine Crowns	Class I	72.9
	Class II	84.5
Illuminated Hardwood Crowns	Class I	86.9
	Class II	70.0
Illuminated Leafless Trees		95.3
Shadowed Pine Crowns		87.1
Shadowed Understory		96.2
Illuminated Understory		90.4

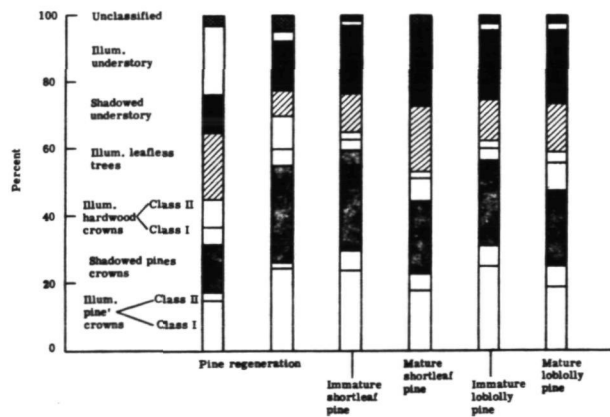


FIGURE 9. PROPORTIONS OF CANOPY COMPONENT SPECTRAL CLASSES THAT OCCURRED WITHIN AREAS REPRESENTATIVE OF EACH FEATURE

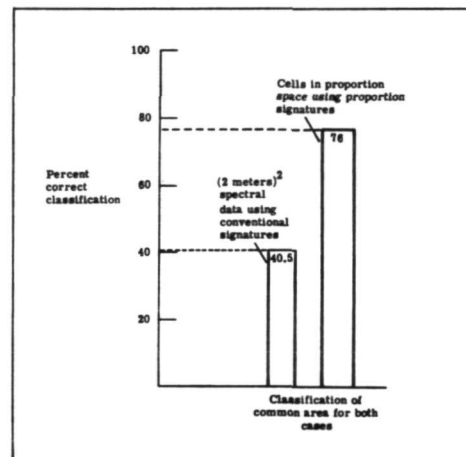


FIGURE 10. COMPARISON OF PROPORTION-SPACE AND CONVENTIONAL CLASSIFICATION PERFORMANCE AVERAGED OVER ALL FOREST FEATURES

REDUCING LANDSAT DATA TO PARAMETERS WITH PHYSICAL SIGNIFICANCE
AND SIGNATURE EXTENSION--A VIEW OF LANDSAT CAPABILITIES

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ABSTRACT

The premise of this paper is that LANDSAT is capable of sensing only a few physical parameters; all computer processing and recognition schemes for LANDSAT data can be successful only to the extent that the desired classifications correlate with, or are designated by, these physical parameters. When this is not the case, automatic recognition results can become highly circumstantial and often hopelessly ambiguous. Although some limited differentiation of plant species can be done by computer processing, most often separation of vegetation types is less dependent on species differences than on differences caused by topography or content of vigorous vegetation. Much of the contrast provided in LANDSAT data is provided by differences in vegetation cover.

Although dominant, vegetation is not the only physical parameter that can be detected with LANDSAT; a ratio of MSS Channel 5 to MSS Channel 4 (R5,4), two visible channels, separates materials by color hue. Additional information is attained by the addition of MSS channels 5 and 4 to approximate brightness, permitting separation of materials by color value. Other spectral combinations may provide correlations with these physical parameters or new ones.

An iron absorption in the infrared can also be recognized in LANDSAT data when iron content is present in sufficient percentages. Although by color, limonite-rich soils are distinctive as bright yellow, they are not unique in the aforementioned R5,4. However, the yellow color imparted to these soils is the result of well disseminated, fine-grained limonite (hydrous ferric oxide) in relatively large quantities. A fairly strong iron absorption is present in the infrared band MSS Channel 7, for these soils, although the wideband configuration of LANDSAT is not optimal for its enhancement and the effects of vegetation often obscure it.

Other such physical relationships are probably available in the spectral configuration of the LANDSAT multispectral scanner and other coming scanners. It is important to isolate and document them so that enhancement, categorical analysis, and image interpretation can better be based upon criteria with physical significance, providing spatial and temporal extension.

1. INTRODUCTION

The view of LANDSAT capabilities presented here and the major premise set forth in the abstract are the distillates of a collection of LANDSAT studies in mineral exploration and land cover classes with which author has been involved. Two data sets available from two of these studies will be drawn upon for illustrative material. The first is a set of laboratory spectra corrected to LANDSAT response, quantitative color determinations, and measurements of iron content for twenty samples of regosols from the Wind River Basin, Wyoming, which were gathered during a study of alteration products associated with roll-type uranium deposits (Salmon and Pillars, 1975). These samples will be used where laboratory measurements are indicated and color designations have been accurately annotated by Munsell standard, as well as by a general color description. The second data set is comprised of field spectra measurements made by personnel of The U.S. Bureau of Land Management on perennial and ephemeral rangeland vegetation types and some soils. These spectra are representative of the natural materials to the extent

that it was possible to fill the field of view of the RPMI* spectrometer with a specific plant or soil in the natural environment; soil color designations are only field descriptions and are not standardized (Bentley, et al., 1977).

The Munsell color system is a widely accepted system of color standardization in use in the United States, especially by geologists and soil scientists. The system is based on a color sphere in which the vertical axis represents color value, the radial axes represent color chroma, and the circumference represents color hue. Notation of Munsell color includes, by convention, the color hue, represented by a number and a letter abbreviation, followed by a number representing color value, a slash(/), and a number representing color chroma, or intensity. An informal color designation of color is sometimes called upon in this paper for ready separation of important visual color differences which are not easily recognized by Munsell designation; most importantly, both tan and yellow samples of regosols in the first data set fall into the 10YR Munsell hue. These have been distinguished with appropriate single letter notation when necessary.

In the discussion of vegetation cover we will follow Maxwell (unpublished report) in assuming a high correlation among biomass, chlorophyll, and leaf water. Recognizing the distinct spectral differences between dead vegetation and green vegetation, when considered in general categories these two will be referred to as "dry" and "green". "Green", a single parameter by definition including leaf water, chlorophyll and biomass, will imply wet-green-biomass.

2. COLOR HUE

Hue is the attribute of color that permits it to be classed as red, yellow, green, blue or an intermediate between any contiguous pair of these. A progression of Munsell hues plotted against LANDSAT response-weighted reflectances for bands 4 and 5 for twenty regosols showed that MSS Band 4 provides better color separation than Band 5, although it is not optimal (Figure 1). Notice that in this figure a progression from YR (yellow-red) to GY (green-yellow) to Y (yellow) colors results.

Spectral ratio values using bands 5 and 4 were calculated from the same data and plotted against full Munsell designation in the order of increasing ratio value (Figure 2). Unlike the single band plots, GY samples are at the end of the progression, which continues from Y to YR. The ratio values not only correlate better than single channels with Munsell hue, but show discontinuities between hue designations. These quantitative differences may be important indicators of LANDSAT MSS capability to separate soil types and to detect surface deposits important for oil and mineral exploration. Ferric oxides in the form of hematite with well-disseminated particles imparting reddish colors to soils and alteration minerals can be enhanced with this single ratio. However, as indicated in Table 1, Munsell hue 10YR contains samples of general description of both tan and yellow, an important distinction to make in geology. Data points in the 10YR range (and one other yellow sample) are annotated in Figure 2 by "Y", indicating a yellow sample, or by "T", indicating a tan sample. The R5,4 did not separate these two colors, their difference being obvious visually. Spectra collected over the whole visible region show definite, promising differences among colors of interest. The nonoptimal LANDSAT configuration does not, however, make optimal use of these differences.

LANDSAT data collected over the Wind River Basin, Wyoming, was used to test how well these laboratory results correspond to actual data. Signatures were extracted from areas known to be well exposed and covered with materials of similar hue to some of the regosol samples which had been measured. Signatures consisted of multiple pixel element samples, the values of which were collected and ratios formed to give R5,4 values, their means and ranges (Figure 3). The anticipated relationship with color hue is borne out, although the ranges of individual sample values often overlap in R5,4 value. This result gives some indication of the realistic capability of this LANDSAT spectral ratio to separate and recognize materials by color hue under limited vegetation cover conditions.

*Bendix Aerospace Systems Division Radiant Power Measuring Instrument

LANDSAT MSS Channel 7, an infrared band, was examined for evidence of possible geochemical information, for there are well known iron absorptions in this spectral region (Rowan, 1972). Spectra and iron content of eighteen of the twenty regosols are shown in Figure 4 with notation of the LANDSAT MSS Channels 6 and 7 superimposed. Yellow samples, which in this case are highest in iron content (and ferric oxide content), are seen to have a strong absorption band in MSS Channel 7. A plot showing R5,4 vs. R6,7 (Figure 5) indicates that using this additional chemical information, separation of yellow and tan on iron content is allowed. The additional separation of colors of interest which would be allowed in a two dimensional system is valid for only those cases where these physical and chemical properties can be expected to retain this relationship.

3. COLOR VALUE

The property of lightness is called color value. Lightness is presumably the result of high reflectance across most of the visible spectrum producing a maximum value in reflected energy when totalled across these wavelengths. No optimization study was conducted here to show that the combination of channels used was the best available for predicting color value; weighting of these channels or some other combination may actually improve color value determinations. However, the simple combination of MSS Band 4 and MSS Band 5 by addition should give an indication of the material returning the highest energy and at least indicate a possibility to recognize this physical property. Figure 6 shows the value of the twenty samples listed in Table 1 plotted against the sum of their MSS Band 4 and MSS Band 5 response-weighted reflectances. General color descriptions are annotated for additional consideration.

Although descriptions of colors were not standardized for the data set made up of field measurements of plants and soils, color relationships of both hue and value for these samples seen in Figure 7 seem to agree with the relationships found for the more precisely determined colors of the soil samples (Figure 2 and 6). In considering these results, allowances must be made for nonoptimal field conditions and possible inconsistencies in color descriptions, but the overall relationships are still strongly indicated. This data set is included to allow the additional consideration of dry and green vegetative material for a more general comparison.

4. INFLUENCE OF VEGETATION

Both color hue and value are important for differentiating among non-vegetative targets because they are indicative of soil characteristics and LANDSAT is spectrally sensitive to these physical parameters. The interplay among rock and soil spectra, natural variation, instrument response, atmospheric conditions, and the influence of superimposed vegetation makes actual recognition and mapping of these characteristics a nontrivial exercise. Discussion of capabilities of LANDSAT to recognize geologic materials without consideration of these factors, particularly vegetation conditions, provides only an estimate of the best results, possible only in ideal data and environments. Much of the terrain in which these materials are to be mapped has at least sparse, partially green, vegetation cover. Increasing percentages of green vegetation would result in so diminishing the distinctive spectral characteristics of the limonitic soils shown in Figure 4 that their LANDSAT spectral uniqueness would be eliminated quickly. Where substantial vegetation interferes with spectral recognition of non-vegetative targets, a method of correcting for vegetation cover must be used simultaneously with spectral parameters which are sensitive to differences in geologic materials.

The LANDSAT multispectral scanner is, by design, sensitive to variations in cover by functioning green biomass. Indeed, we have stated that much of the spectral contrast available in LANDSAT data is provided by extremes in vegetative cover and that without these, many automatic recognition procedures could not make the differentiations which appear possible. A ratio of infrared to red is often drafted for enhancement of vegetation cover differences because it is relatively insensitive to background variation and very sensitive to wet-green-biomass. Figure 8 shows the relationship of R7,5 measurements of rangeland vegetation and soils. Note that most of the useful dynamic range of R7,5 is the result of

differences in the spectra of green vegetation--and likewise differences in their spectral contribution in LANDSAT data due to variation in ground cover--with little meaningful separation among rocks and soils.

R7,5 and other single ratios may not be optimal for recognizing vegetation, either for correcting for its interference with geologic targets or for land cover type mapping. Optimal combinations of MSS bands or highbred spectral parameters may, for any particular environment or time of year, be found by a number of linear and polynomial optimization methods. A relatively simple combination of ratios we have tried uses the vegetation information available in the R7,5 ratio with color information supplied in R5,4. While R7,5 is the highest for high vegetation cover, it can also be high for common iron oxides. However, R5,4 will always be at a minimum for things which appear green and high for red ferric iron oxides. Dividing R7,5 by R5,4, one would expect vigorous plant material which is high in the numerator and low in the denominator to become even more separated to the high end of the values. This ratio of ratios allows the range for green plants in soils ranging in color from red to white to expand slightly from that available in a single ratio.

Most importantly, the influence of vegetation is treated in these methods as a continuous, unique variable. Other such physical parameters which may be possible to isolate using LANDSAT data, particularly with the additional information allowed by registration of multiple-date data sets, are percent grass, grass/shrubs within vegetation, etc. It is the significance of those physical parameters which can be isolated in some spectral dimension in LANDSAT data to the definition of plant communities or crop types that will determine the success of recognition in the spectral signature approach. The physical basis for spectral differences among targets is sometimes not analyzed. As a result, the vegetative or soil characteristics which are most influential in the spectral signature do not necessarily become apparent. Whether a plant community is recognizable in a particular data set because of differences in soil, plant species, or vegetation cover is not evident when employing automatic recognition. This can be a drawback, since the ability to recognize these same plant communities in another data set or in another area is contingent on which of these factors contributes most to its uniqueness.

Although the author is unaware of any quantitative studies which have documented the range of percent vegetation cover over which the R7,5 or other spectral parameters for predicting vegetation cover are sensitive, much qualitative data indicates that accuracy falls off well above those percentages important for mapping vegetation in tasks such as desertification mapping, ephemeral rangeland condition and rangeland trend, and perhaps even some crop identification. In a recent study in ephemeral rangeland in Arizona, we found that the open growth characteristics of desert trees and shrubs and the low percentages of ground cover by live plant material created a diffuse target highly influenced by the background soil and rock. Figure 9 shows the ranges of LANDSAT single channel values for thirteen targets extracted from separate plant community sites in an area west of Phoenix, Arizona, for May, 1975. Little separation is available in any of the data for these plant communities, which range from 3 to 24 percent vegetation cover.

Difficulties in recognizing the expected influence of vegetation in arid regions of sparse cover have precedence in the literature. In his reply to Jackson and Idso (1975), Otteman reports an observed low reflectance in MSS Band 7 in an area of appreciable vegetation cover in the Western Negev and refers to it as "the Negev infrared reflectance paradox". The apparent explanation for the anomalous reflectance of the area was that even with 25 to 35 percent ground cover, it was the interstitial soil that effectively controlled the reflectances. In the Negev the interstices showed dark-gray plant litter and stabilized soil. In contrast, interstitial soil reflectances were high in the adjoining Sinai, where unstabilized soil with a high albedo was well exposed under a mere 10 percent vegetation cover. This observation would seem to be in agreement with the work of Baldrige, et al. (1975) in the widely different environment of the State of Ohio. In land use inventory categories designated for the mapping of land use in Ohio, the most dense industrial and commercial areas classed as "urban" were grouped into a vegetation cover class of 0 to 35 percent vegetation cover.

5. RECOGNITION OF PLANT SPECIES

Certainly some influences of plant species' reflectance properties are present in LANDSAT data. The important question is which, if any, can be distinguished spectrally from differences in vegetation cover. When species differentiation is inferred from information which actually depends on vegetation cover differences, the latter should be specified precisely as the distinguishing physical parameter. Not only is it less misleading, but optimal processing functions can then be adjusted systematically for differences in growing season, climate, background, etc..

In the study of perennial rangeland in Montana, two of the plant communities defined during fieldwork were upland grass, a mixture of grasses, sedges, and bushes with 46 percent ground cover, and bluestem hillside, with 47 percent ground cover chiefly made up of Andropogon scoparius, or "little bluestem". In a single channel of LANDSAT data (MSS Channel 5) these two plant communities differed, most likely because of their correlation with prominent topographic differences. A ratio R7,5 of the same area showed no difference between the two plant communities, although considerable variation in vegetation cover within the upland grass plant community became evident.

Two other plant communities with very different vegetation characteristics, a wet meadow with 75 percent vegetation cover and a pine-bunchgrass community with 59 percent cover (where it occurred on north facing slopes) were equally dark in MSS Channel 5. Pine-bunchgrass stands on other exposures looked similar to upland grass plant communities also present. The unique reflectance properties of pine needles and leaves of other evergreens provide a strong influence which can possibly be used in species identification. However, it and other species determination must be represented in a spectral dimension independent of vegetation cover influences for operational mapping potential.

6. CONCLUSION

The consequences of this view of LANDSAT capabilities are of major importance to operational procedures being designed by The U.S. Bureau of Land Management in their newly assigned task of keeping a current inventory of the natural resources of public lands. Species differences is crucial information for estimating conditions for grazing. The recognition of plant communities in natural environments is somewhat more difficult than in agricultural areas where, for a field of a certain size, a discrete, homogeneity of target can be assumed. In rangeland and forested environments, there can be a continuous blend of species, their phenologies can differ according to weather conditions, and apparent cover can change differentially due to specific canopy characteristics. The separation of vegetation characteristics due to differences in the cumulative wet-green-biomass present and those that are truly indicative of species' spectral differences can lead to a better understanding of LANDSAT capability to map vegetative types in both natural environments and agricultural areas. In addition, specific attention to the physical conditions which bound LANDSAT capabilities may prevent planning of future mapping and recognition efforts when spectral resolution may not be sufficient, such as plant community mapping in areas with less than 25 percent vegetation cover.

The implications of this view are equally important to land use studies which require classification in greater detail than Level I land use. Separation of even Level I with LANDSAT multispectral processing is highly dependent on vigorous vegetation extremes to provide contrast, as well as to characterize classes such as "old residential" or "park areas". Spectral processing actually recognizes land cover rather than land use. Land cover characteristics can vary with climate, city layout, and residential development. Spectral recognition will vary with these local land use practices. Where vegetation cover is not significantly different among land use classes, or where contrast due to extremes in vegetation is not available, the accuracy of land use mapping will be seriously degraded.

Geologic applications must be performed for specific tasks and in those environments where physical characteristics also fall within the spectral and spatial capabilities of LANDSAT data. For mineral exploration, target deposits

must first fit the basic criteria of possible spectral distinction and sufficiently large surficial expression. Then it must be determined that compositional differences which are important to discovery of the deposit have spectral characteristics strong enough for detection above noise and vegetation present in the data. This may require restatement of specific questions such as "Can LANDSAT help discover new deposits of uranium?" to "Under what conditions can LANDSAT help discover new deposits of uranium?" Details of vegetation conditions and the color of oxidization products associated with the uranium deposits are inextricable from the answer to be given; it is the germane physical parameters which define a successful application of LANDSAT multispectral data to earth resource investigations.

ACKNOWLEDGEMENTS

We acknowledge the support of the Energy Research and Development Administration under contract No. AT(05-1)-1635 and The United States Bureau of Land Management. Much of the data collection and research on which evaluation of rangeland applications is based was accomplished through the efforts of R. Gordon Bentley, Jr., and William J. Bonner, although the author is solely responsible for qualitative judgments expressed herein.

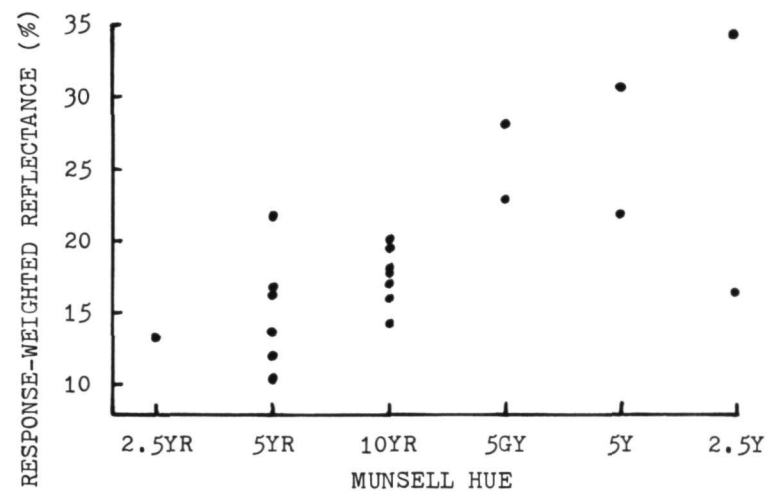
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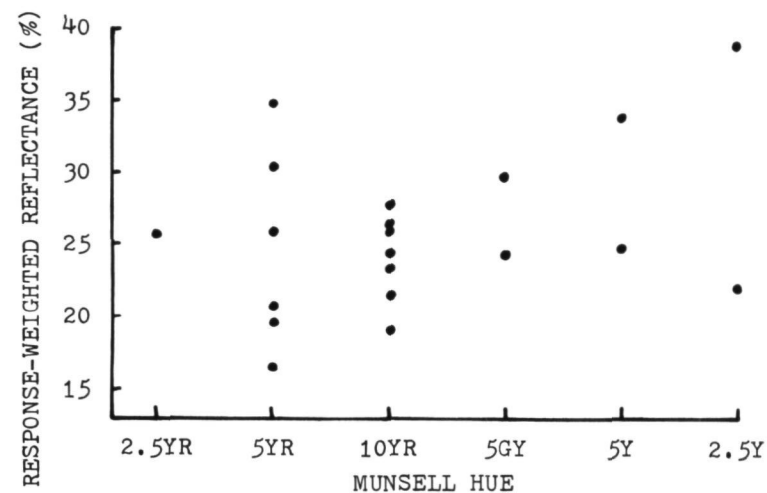
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MUNSELL COLOR	GENERAL COLOR AND ABBREVIATIONS	
5 YR 5.5 / 8	Dark Orange; (Nugget ss)	(Or)
5 YR 7 / 8	Light Orange; (Nugget ss)	(Or)
2.5 YR 4.5 / 6	Bright Red; (Chugwater Fm.)	(R)
5 YR 4 / 6	Dark Red-Brown	(R)
5 YR 4 / 4	Bright Red	(R)
5 YR 5 / 6	Pale Red	(R)
5 YR 5 / 4	Pale Red	(R)
10 YR 5 / 6	Yellow	(Y)
10 YR 6 / 5.5	Yellow	(Y)
10 YR 4 / 6	Yellow	(Y)
10 YR 5 / 5	Yellow	(Y)
2.5 Y 6 / 6	Yellow	(Y)
10 YR 5 / 3.5	Tan	(T)
10 YR 5 / 3	Tan	(T)
10 YR 6 / 3	Tan	(T)
2.5 Y 8 / 2	White to Pale Orange	(W)
5 Y 6 / 4	Yellow-Green	(YG)
5 Y 6 / 2	Pale Yellow-Green	(YG)
5 GY 7 / 2	Blue-Green	(G)
5 GY 6 / 2	Green	(G)

TABLE I. COLOR DESIGNATIONS OF REGOSOLS FROM THE WIND RIVER BASIN, WYOMING.



(a) Band 4 (Green)



(b) Band 5 (Red)

FIGURE 1. LANDSAT RESPONSE-WEIGHTED REFLECTANCES FOR MSS BANDS 4 AND 5 VS. MUNSELL HUE FOR 20 REGOSOLS IN THE WIND RIVER BASIN, WYOMING.

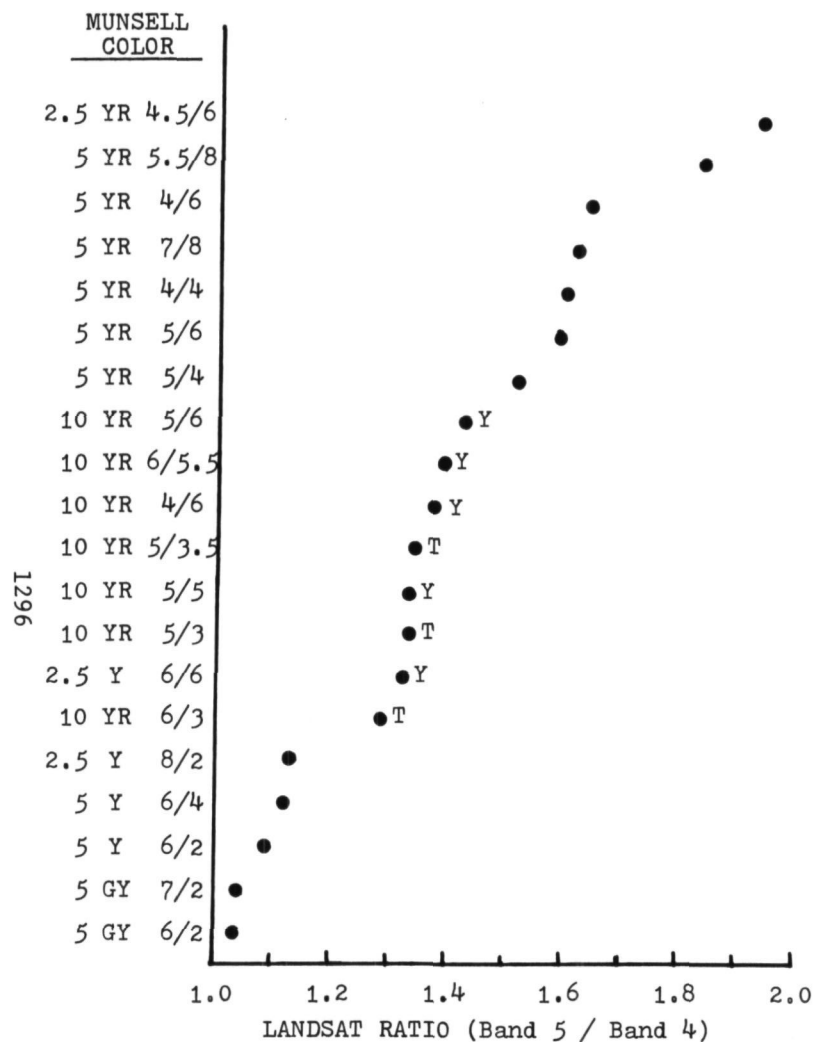


FIGURE 2. MUNSELL COLOR VS. INCREASING LANDSAT R5,4
VALUE FOR 20 REGOSOLS IN THE WIND RIVER BASIN, WYOMING

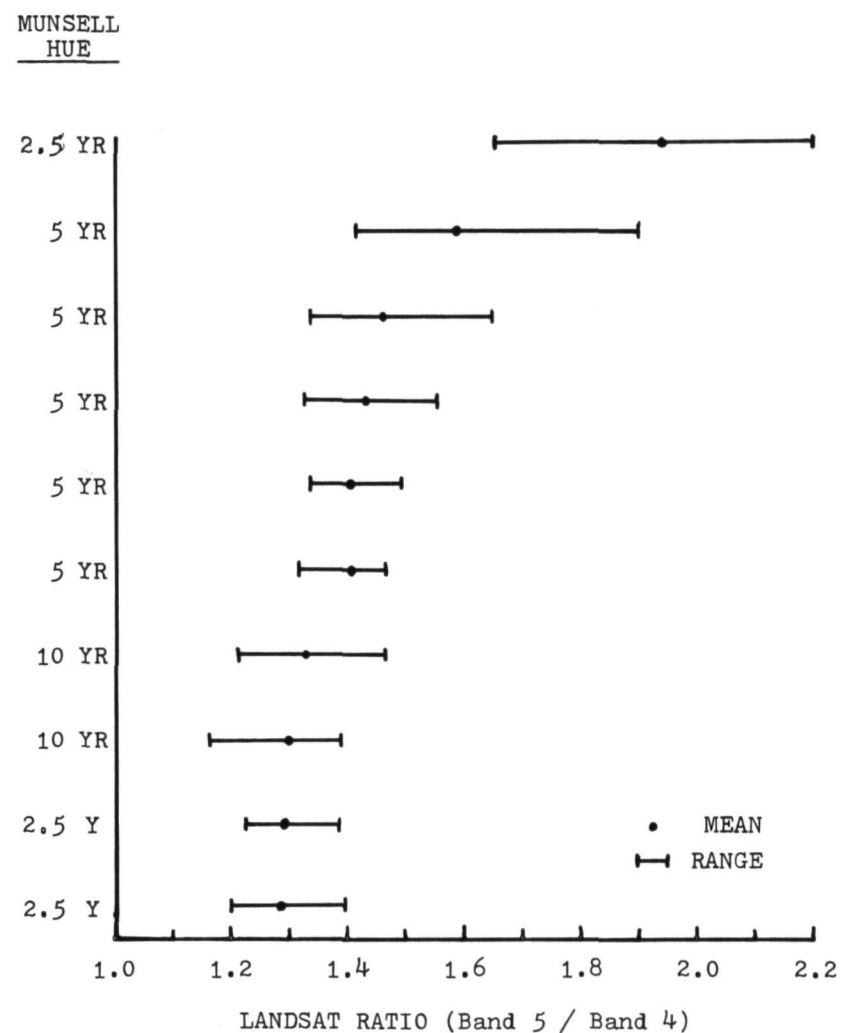


FIGURE 3. MUNSELL HUE VS. LANDSAT R5,4 SIGNATURES
CALCULATED FROM DIGITAL VALUES OF LANDSAT DATA COLLECTED
OVER THE WIND RIVER BASIN, WYOMING, AUGUST, 1972.

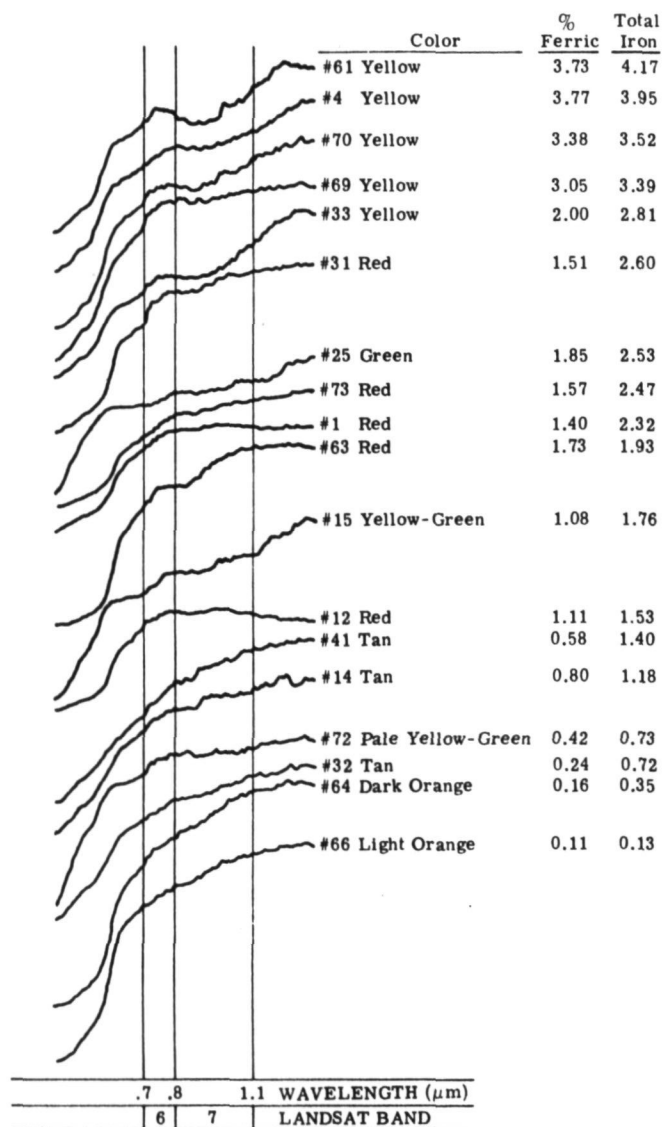


FIGURE 4. INFRARED SPECTRAL FEATURES IN ORDER OF DECREASING TOTAL IRON CONTENT (and general color).

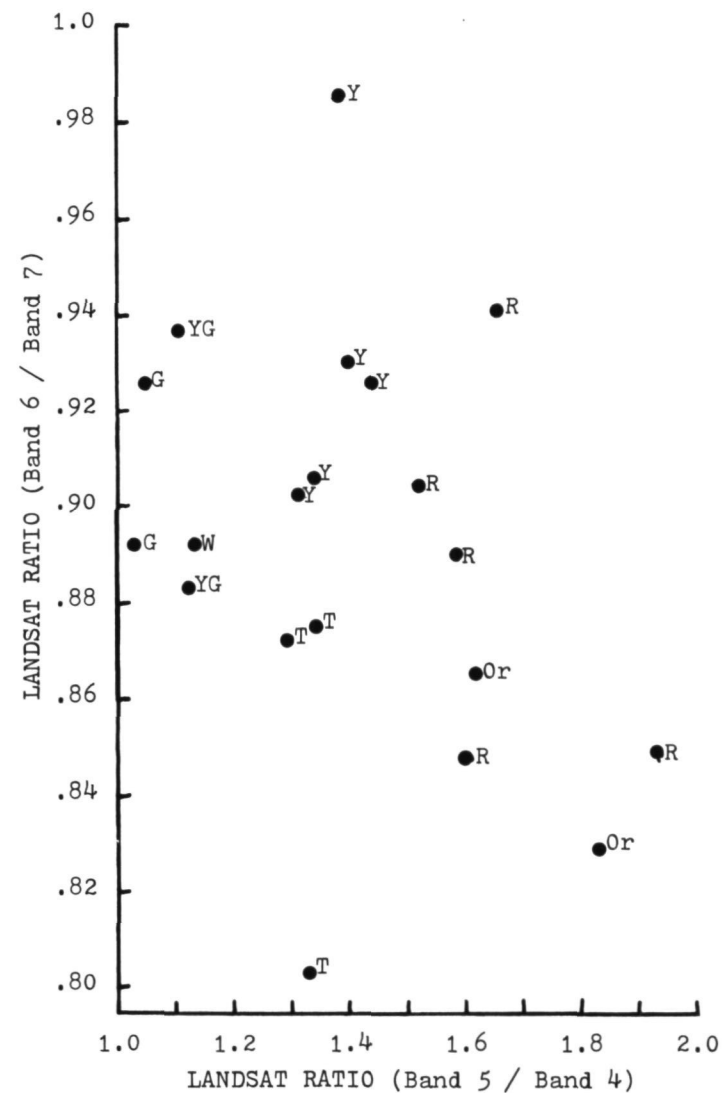


FIGURE 5. LANDSAT R6,7 VS. LANDSAT R5,4 FOR 20 REGOSOLS IN THE WIND RIVER BASIN, WYOMING.

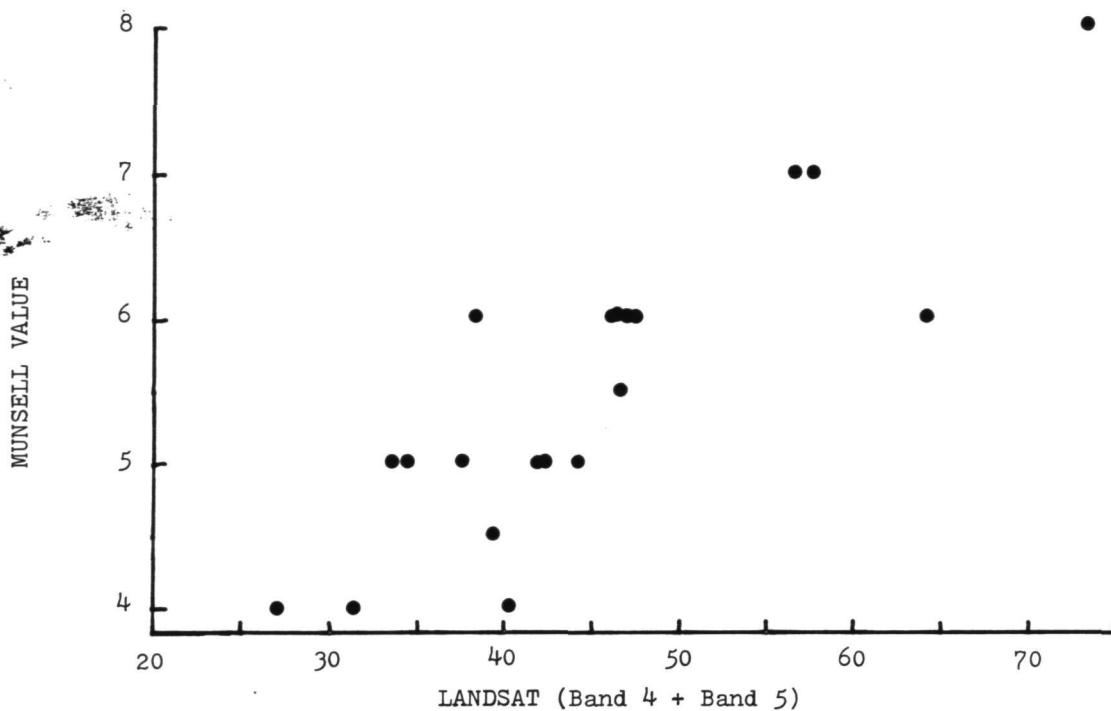


FIGURE 6. MUNSELL VALUE VS. LANDSAT (Band 4 + Band 5) CALCULATED FROM RESPONSE-WEIGHTED REFLECTANCES FOR 20 REGOSOLS IN THE WIND RIVER BASIN, WYOMING.

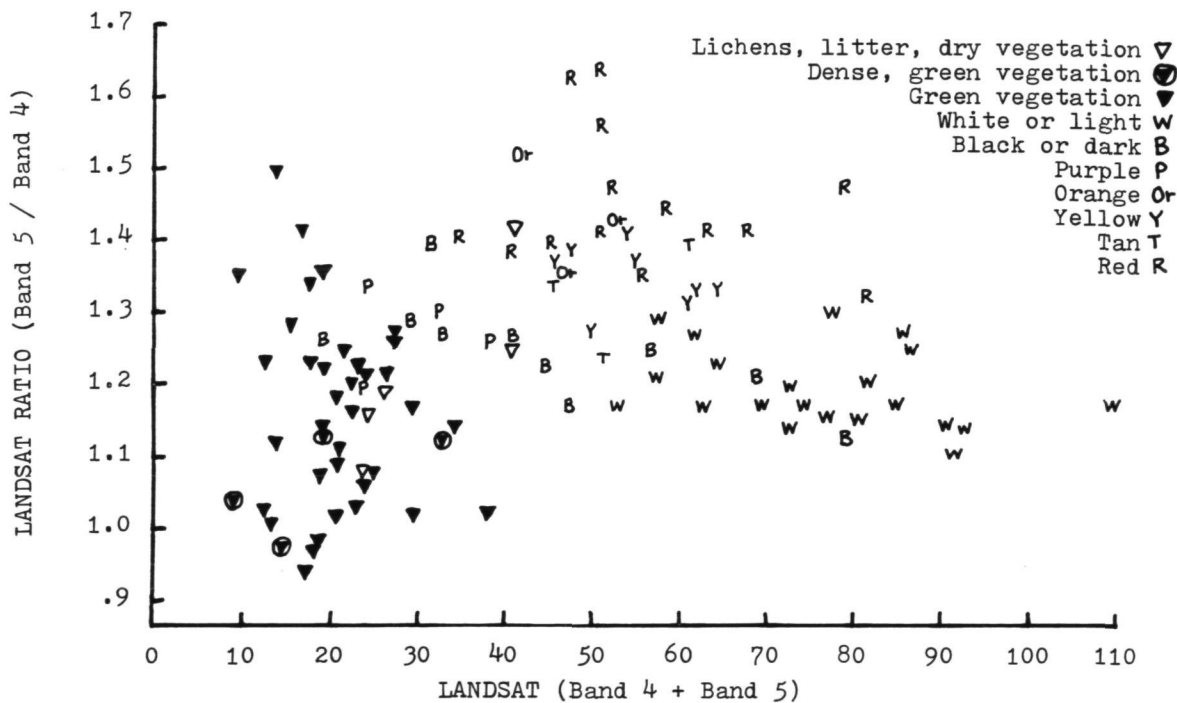


FIGURE 7. LANDSAT R5,4 VS. LANDSAT (Band 4 + Band 5) CALCULATED FROM FIELD SPECTRA OF RANGELAND PLANTS AND SOILS IN EASTERN MONTANA.

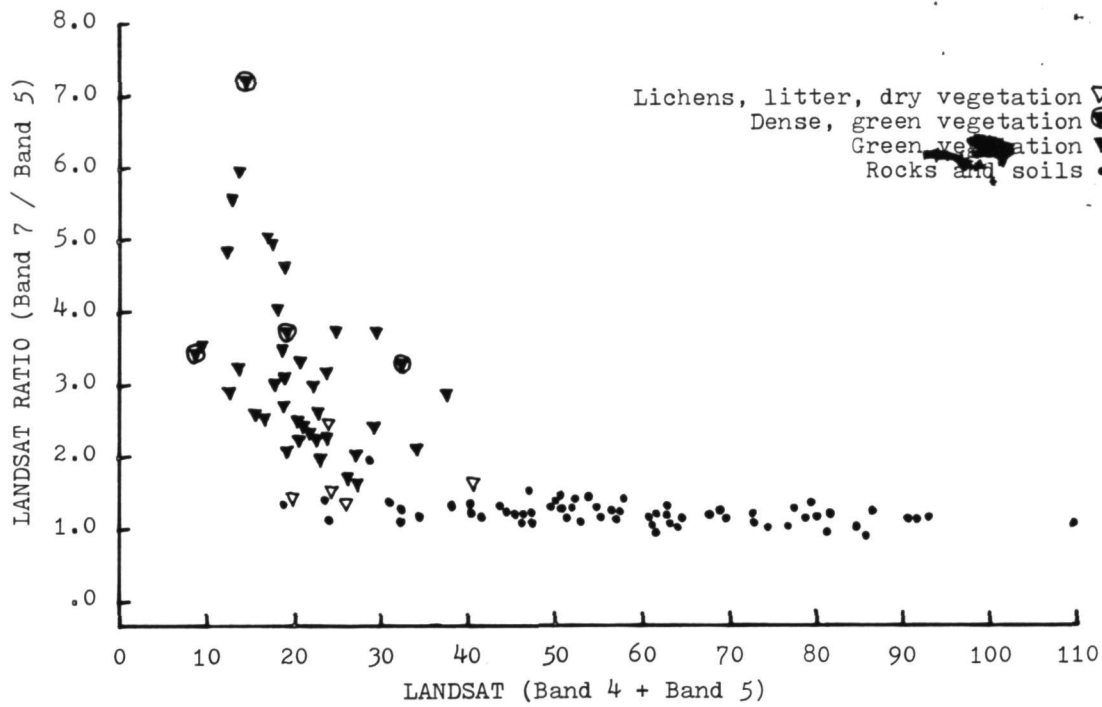


FIGURE 8. LANDSAT R7,5 VS. LANDSAT (Band 4 + Band 5) CALCULATED FROM FIELD SPECTRA OF RANGELAND PLANTS AND SOILS IN EASTERN MONTANA.

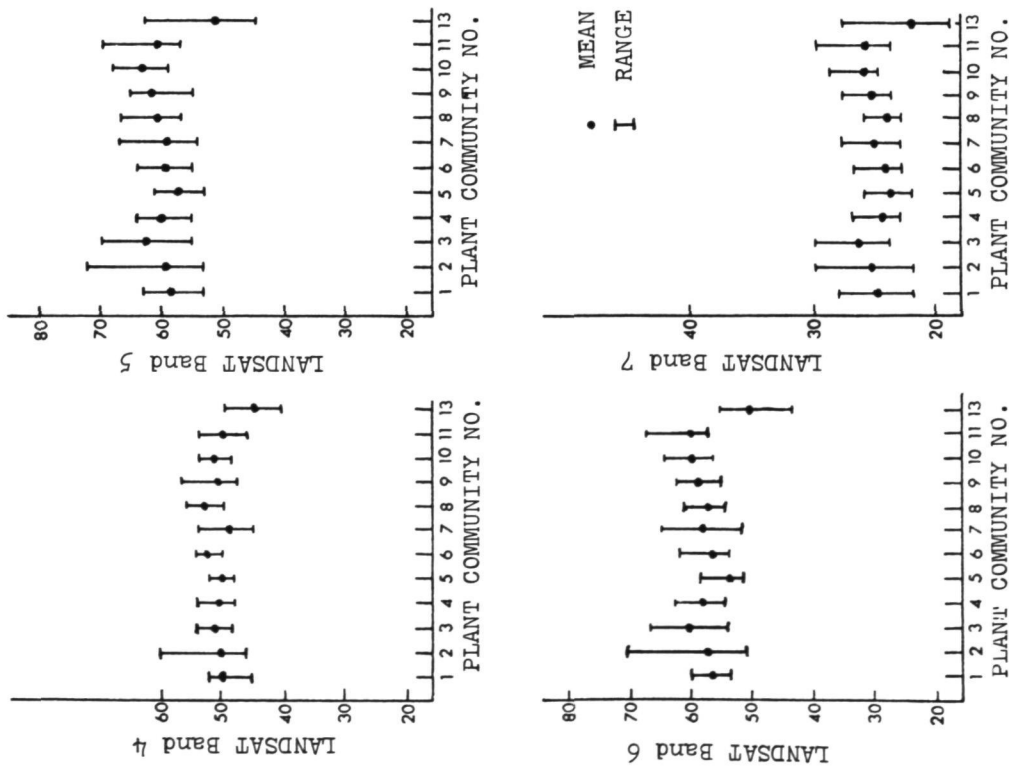


FIGURE 9. PLANT COMMUNITY SIGNATURES EXTRACTED FROM LANDSAT DATA FOR EPHEMERAL RANGELAND IN ARIZONA WITH 3 TO 24 PERCENT VEGETATION COVER, MAY, 1975.

AERIAL ALBEDOS OF NATURAL VEGETATION IN SOUTH-EASTERN AUSTRALIA

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ABSTRACT

70 mm black-and-white low-level photography was used to record the track of the aircraft, which was then plotted on conventional 1:80,000 23 cm photogrammetric photographs and referenced against simultaneous measurements of the beam albedos of vegetation. Using stereo-pairs of the 70 mm photographs, the vegetation was classified into sub-formations. Marked differences in the sub-formation albedos were observed. A two-way table using stand height and crown cover of the sub-formations clearly showed a very distinctive trend of albedos. This finding may be important in other vegetal studies.

1. INTRODUCTION

Previously (Howard, 1970), a method for the stereoscopic profiling of natural vegetation from aerial photographs was outlined and a two-way aerial photographic classification of vegetation presented. This study was followed in 1972 in south-east Australia by the measurement of albedos of a range of major plant communities (i.e. formations/sub-formations, sensu Beadle & Costin, 1952); and included several sub-formations examined in the 1970 study. The results of the albedo study are presented in this paper.

2. METHOD

Albedo (L) is the fraction/percentage of incident solar radiation (S_i) which is reflected (S_r) from the earth's surface, including its vegetation. Beam measurement simply implies that the radiation is measured with a narrow-beam radiometer. In the present study, a thin glass twin-domed radiometer (Funk-type pyranometer) was mounted on the roof of the aircraft (i.e. Cessna 172, 182) for recording incident solar radiation in flight. A vertically downwards pointing beam instrument (4° angular field) was mounted on a specially designed plate, external to the aircraft fuselage, for recording simultaneously the reflected solar radiation from the plant communities. The transduced signals from the radiometers were then recorded in millivolts on a Toa paper-chart recorder housed in the rear of the aircraft.

In order to calculate an albedo (L_b) from the aerial recordings, it was necessary to apply a conversion factor to the beam measurements. This conversion factor (C) was separately determined (see Howard & Barton, 1973) i.e. $L_b = \frac{S_r}{S_i} \times C$.

In addition, a 70 mm format Vinten camera (fig. 2) was mounted alongside the beam short-wave radiometer, so that a permanent photographic record would be obtained of the vegetal surfaces being studied. The 70 mm aerial photographs enabled the track of the aircraft (and beam radiometer) to be plotted on small-scale photogrammetric photographs (e.g. 1/80,000) and, from this, an appraisal made of the ground areas covered by the plant sub-formations and their related albedos. All measurements were recorded under clear sky after several rain-free days and at a flying height of 330 m above ground datum. Each series of measurements across a plant sub-formation covered a distance of at least 5 km and frequently 50 km. Several of the sub-formations were covered on more than one occasion between 1100 hours and 1400 hours meridian time, March to August, 1972. At time of recording, the sun's elevation varied between

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25° and 40°. On the 22nd June (mid-winter), its maximum elevation was 28°.

3. RESULTS

The location of the plant sub-formations, above which the albedos were measured, are shown in fig. 1. It will be observed that measurements extend across mesic communities near the coast (144°E, 37°S), across mesic communities on the Great Dividing Range (145°E, 37°S) to communities in conditions approaching semi-arid to the north of the river Murray (143°E, 34°S). The numbers on the map are cross-referenced with Table A. Table A lists the sub-formations (Sensu Beadle & Costin, 1952) and provides information on solar irradiance (incoming short-wave radiation) and reflected solar radiation (out-going short-wave radiation). The table also gives the derived albedos and the mean albedos for each sub-formation. Each recording listed in columns 3 and 4 indicates a separate flight. The terms forest, woodland, shrubland and grassland correspond to Raunkiaer's size classes (1934): megaphanerophytes, mesophanerophytes, microphanerophytes and nanophanerophytes/chamaephytes. Raunkiaer's size-classes provide a useful basis for the physiognomic classification of major plant communities recorded on aerial photographs.

Fig. 3 are copies at contact scale (1/4000) of photographs taken with the vertically mounted Vinten 70 mm camera at the time of the albedo measurements. From these photographs the crown cover percent of the woody vegetation can be measured and the approximate height of the woody vegetation determined by parallax bar measurements. In Table B the sub-formations, across which albedo measurements were recorded, have been classified on the basis of stand height and crown cover (sensu Howard, 1970a, 1970b) and their mean albedos from Table A also entered in the table.

4. DISCUSSION

An examination of the albedos given in Table A draws attention to the marked differences in the albedos of tall woody vegetation and grassland or land on which the tall woody vegetation is sparse (e.g. tree savanna). Short woody vegetation (e.g. blue bush, saltbush) has a high albedo, which is between the albedos of grazed and ungrazed grassland. Probably the low albedo of the two forest types is the result of the relatively very rough surface these present to the incoming solar radiation.

Table B is of considerable interest. The albedos entered in this table show a distinctive trend and provide order to what in Table A may appear to be disorder. For the megaphanerophytes (forest), the mean albedos increase from .079 for wet sclerophyll forest to .105 for open dry sclerophyll forest. For mesophanerophytes (woodland), the trend is from .098 (tall woodland) through .116 (cypress pine woodland — *Callitris glauca* France) to .165 (Tree savanna). For the microphanerophytes (shrubland) and nanophanerophytes/chamaephytes mean albedos increase from 0.96 for Big Mallee to .140 for saltbush (*Altriplex vesicaria*) and to .155 for bluebush (*K. pyramidata*, *K. sedifolia*).

The high mean albedos of the nonophanerophytes and chamaephytes possibly provide an explanation for the increasing albedos of the megaphanerophytes and mesophanerophytes with the decreasing crown cover of the dominant woody strata. As the tree cover decreases, so the herbaceous ground cover becomes more exposed to incoming solar radiation and therefore contributes more to the reflected solar radiation of the plant community. Even grazed grassland has a high albedo (.135); but the albedo of ploughed land is lower (.107). However, the micro-structure of ploughed soil is rough. Water has a very low albedo (.018) and this is seen as contributing to the low albedo of swamp (.060). The albedo of water was observed to vary with colour (i.e. sediment content), but is not reported on here as it requires a separate study. Whether a wide range of structural types of vegetation can be identified by their albedos needs further investigation. An examination of table A shows that, although the mean albedo (L_b - column 6) may be distinctive for some of the sub-formations, there is often an overlap of their albedos (L_o , column 5). The overlap of dry sclerophyll forest and tall woodland is not surprising, since the criteria of height and crown cover or height and crown diameter often give conflicting field classifications. The similarity of the albedos of dry

sclerophyll forest, tall woodland and big mallee, occurring under quite different climatic regimes, is interesting and suggest some unidentified unifying factor. Each are communities of dominant eucalypts; and, perhaps, this is associated with their leaf area indices. Wet sclerophyll forest and shrub woodland, the only other eucalypt dominant communities are distinctive from these by their well developed woody under storey.

The orderly sequence of albedos, when placed in a two-way photo-physiognomy table (Table B) draws attention to the importance of size class/dominant height and gross cover of the ground by woody vegetation as parameters influencing the albedos of natural surfaces. The photo-physiognomie table per se was developed previously by the author (Howard, 1970a, 1970b) as means of classifying vegetation in Australia directly from aerial photographs and as such has been extended to the vegetation of East Africa (Howard, 1970a). The logical fit of the albedos into the vegetal table is also seen as emphasizing the usefulness of this kind of table for classifying vegetation from aerial photographs and implies, perhaps, that albedos as recorded on satellite imagery could be used as a basis to vegetal classification.

5. ACKNOWLEDGEMENT

The author is indebted to the Reserve Bank of Australia, whilst at the University of Melbourne, 1970-72, for financing the study, appreciates the interest shown in the study by C.S.I.R.O. (Aspendale, Deniliquin) and acknowledges the field and technical assistance given by Dr.I.J. Barton, University of Melbourne.

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TABLE A — Major plant sub-formation, their reflected radiation and albedos and solar irradiance — S.E. Australia, 1100-1400 hours. March/August 1972.

Map no.	Plant sub-formation	Solar Irradiance mWcm^{-2} (si)	Reflected Radiation mWcm^{-2} (Sr)	Beam albedo (Lb)	Mean albedo (Lb)
1	Wet sclerophyll Forest	51,74,83	4.8,6.1,5.1	.094, .082, .062	.079
2	Dry sclerophyll Forest				
	Dividing Range	53,73,85	4.8,6.4,7.6	.091, .088, .089	.090
3	Dry sclerophyll Forest				
	Riparian — with moira grass	65,65,64	7.4,6.1,7.9	.114, .093, .108	.105
4	Big Mallee	57	5.5	.096	.096
5	Savanna Mallee	66	6.6	.100	.100
6	Tall Woodland	54	5.3	.098	.098
7	Cypress pine Woodland	31,71,54	4.0,7.2,5.3	.133, .101, .098	.116
8	Shrub Woodland	33,34	4.1,4.3	.124, .126	.125
9	Tree Savanna	66	10.0 to 11.8	.151 to .179	.165
10	Steppe (Saltbush)	59,67,62	8.9,9.2,9.7	.150, .137, .134	.140
11	Steppe (Bluebush)	66,67	10, 10.6	.152, .158	.155
12	Grassland (Native ungrazed)	56	8.7	.155	.155
13	Grassland (grazed)	57	7.7	.135	.135
14	Water	76	1.4	.018	.018
15	Swamp (Murray red gum)	57	4.1,3.0	.064, .057	.060
16	Bare ground: Ploughed (dry reddish brown soil)	74,69,55	7.4,6.9,6.6	.100, .100, .120	.107

TABLE B — Two-way photo-physiognomic classification of woody vegetation using dominant height and gross cover of the woody vegetation. Albedos shown in brackets.

Life form	Megaphanerophytes	Mesophanerophytes	Microphanerophytes	1 Nanophanerophytes 2 Chamaephytes
Size class - Raunkiaer (Height - M)	30	8.30	2.8	1 0.25-2.0 2 0.25
Gross cover (dominant woody strata) c. 100%	Wet sclerophyll Forest (.079)			
Very dense e.g. 75%	Dry sclerophyll Forest (.090)	Tall woodland (.098)		
e.g. 10-50%	Dry sclerophyll Forest (.105)	Cypress pine woodland (.116) Shrub Woodland (.125)	Shrubland Big Mallee (.096) Savanna Mallee (.100)	Steppe. Saltbush (.140) Blue bush (.155)
Open e.g. 10%		Tree Savanna (.165)		Grassland (.155)

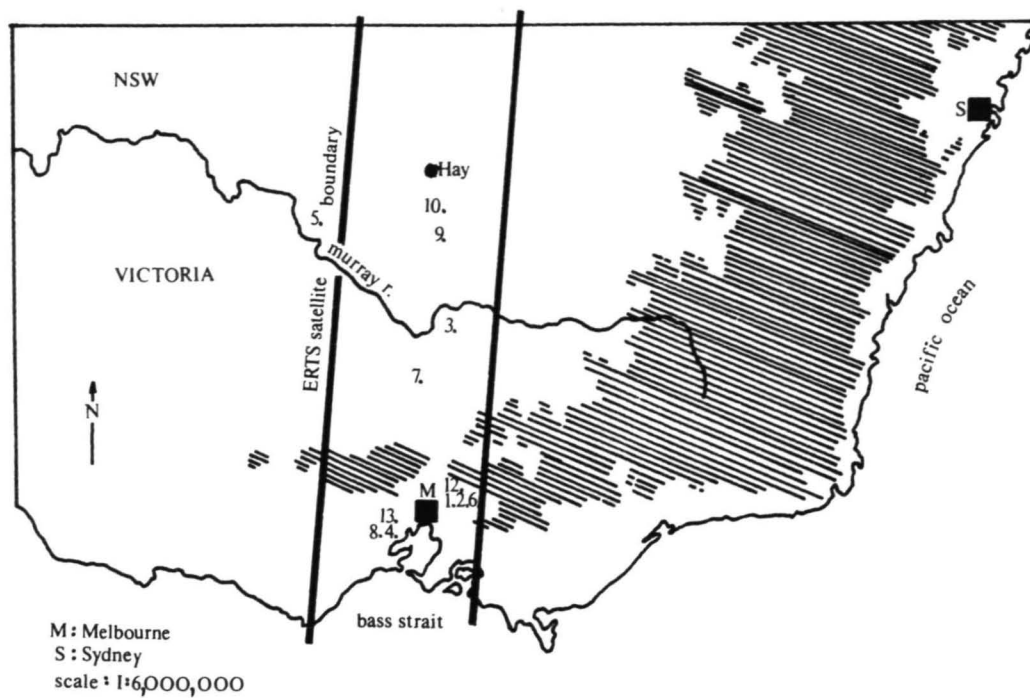


Fig. 1. Map of south-eastern Australia showing the location of the albedo sampling areas (cf. Table A).

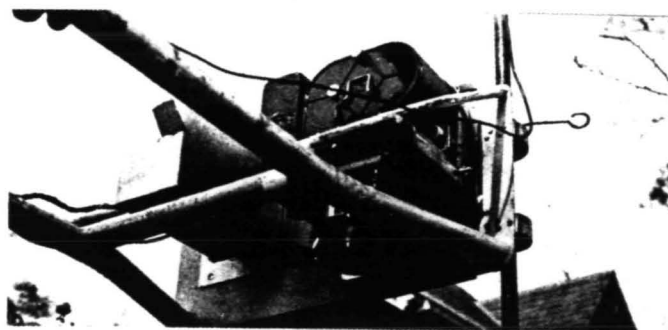
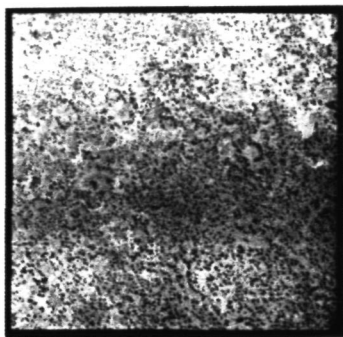
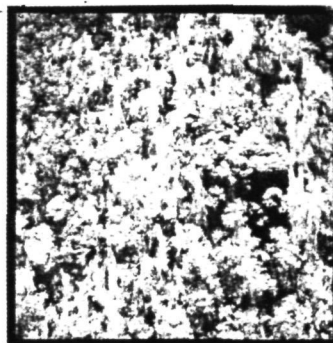


Fig. 2. Short-wave beam radiometer and 70 mm camera used on plate external to aircraft fuselage.

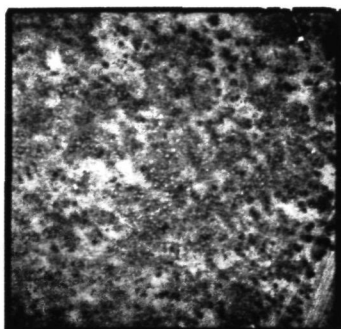
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(A)



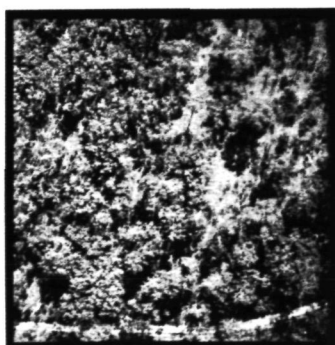
(B)



(C)



(D)



(E)



(F)

Fig. 3. 70 mm vertical aerial photographs of plant sub-formations over which albedos were measured. (a) Steppe - saltbush (b) Shrubland - mallee (c) Woodland - *Callitris glauca* (d) Woodland - shrubs and small trees (e) Forest - dry sclerophyll (f) Forest - wet sclerophyll

BLOB: AN UNSUPERVISED CLUSTERING APPROACH TO SPATIAL PREPROCESSING
OF MSS IMAGERY*

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ABSTRACT

A basic concept of MSS data processing has been developed for use in agricultural inventories; namely, to introduce spatial coordinates of each pixel into the vector description of the pixel and to use this information along with the spectral channel values in a conventional unsupervised clustering of the scene. The result is to isolate spectrally homogeneous field-like patches (called "blobs"). The spectral mean vector of a blob can be regarded as a defined feature and used in a conventional pattern recognition procedure. The benefits of use are: ease in locating training units in imagery; data compression of from 10 to 30 depending on the application; reduction of scanner noise and consequently potential improvements in classification/proportion estimation performances.

1. INTRODUCTION

For processing of MSS data, improved methods of extraction of training data, of data compression, and of classification/proportion estimation are needed. A basic technique which creates opportunity for improvements in all these aspects of MSS data processing has been developed. The basic technique is to incorporate the rudimentary concept of spatial nearness into the preprocessing steps in a simple and natural way, and to extract, as features, spatially homogeneous units from the MSS image. Incorporated into a complete processing system for MSS data the technique is helpful in all of the above mentioned ways.

2. DESCRIPTION OF BLOB

The basic technique is incorporated in an algorithm called BLOB [1]. It consists of augmenting each pixel vector with two additional components which describe the pixel's spatial coordinates (i.e., the line number and the point number). These augmented pixel vectors are used in a conventional clustering algorithm [2] to accomplish "spectral-spatial" clustering. Spatially and spectrally similar pixels are grouped together in each cluster (called "blobs"). In an agricultural scene the result is to build field-like structures, as shown in Figure 1. Figure 1 is a typical unsupervised blob map of an agricultural scene.

Ten grey levels were chosen for this display and these are assigned to the blobs in an arbitrary manner. The most notable characteristics of BLOB which can be observed in this figure are the use of spatial information to smooth over noise in individual pixels, and the treatment of boundary pixels. These will be discussed in more detail in following sections.

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[NOTE: Extensive preprocessing steps, in addition to blobbing, are routinely incorporated in ERIM's processing of Landsat MSS data and are in part responsible for the overall quality of the results presented [3]. Briefly, these steps include: screening, to identify clouds, cloud shadow, water, and bad (excessively noisy) pixels and to calculate diagnostic features for later use in atmospheric effects correction; satellite correction, to normalize Landsat 1 data to be commensurate with Landsat 2; solar zenith angle correction, to normalize data collected at various zenith angles to a single zenith angle; atmosphere (haze) effects correction, to normalize data collected under a variety of haze conditions to a single standard haze condition using the XSTAR algorithm [4]; Tasselled Cap transform [5], producing a set of linear combination features which emphasize physical characteristics of the data, primarily soil brightness and green vegetative development; and multitemporal augmentation, combining registered data from passes at two or more times.]

2.1 FEATURE EXTRACTION

The important information about each blob is recorded and comprises a compressed feature description of the scene. Two outputs are produced: a pixel output tape which defines for each pixel which blob it belongs to, and a blob feature output tape containing a redefined set of features for each blob. These features include the mean vector of all the pixels contained in the blob (or alternatively, only the interior pixels, as discussed in the next section) and the number of points in each blob. The blob mean vector includes the line mean and the point mean which serve as a description of the position of the blob in the scene.

2.2 EXTRACTION OF TRAINING UNITS

For purposes of training a classifier one would like to use only pixels which are "pure" examples of the classes of materials being trained. Thus, it is desirable for purposes of training to strip away boundary pixels, i.e., pixels of a given blob which are adjacent to another blob. The pixels remaining after stripping are nearly always pure pixels, and constitute "stripped blobs".

Figure 2 shows a segment of Landsat data which has been subjected to multi-temporal spectral-spatial clustering, using four dates as follows:

23 October 1973 9 May 1974 27 May 1974 14 June 1974.

In Figure 2, the ground-truth field lines (and field numbers), and an encompassing rectangle are overlaid on the blob presentation. In this presentation the field center pixels are left blank while near-boundary pixels are shown as asterisks. This results in some fields being entirely missing, since they were formed into such small initial blobs. This is no particular drawback since such small or ragged fields aren't likely to make very good candidates for training fields anyway. Some large fields are converted into two blobs and so would be used as two separate training fields.

In several cases throughout the scene blobs run across field boundaries. We have identified 13 such cases. In 10 out of 13 cases the adjacent field ID's match. In two of the cases the infringement of the blob across field boundaries amounts to only a few pixels. One case is unexplained. This is fairly typical of our experience, namely that blobs seldom cross the boundary between two spectrally distinct classes.

2.3 TRAINING AND CLASSIFICATION

Having identified pixels which are suitable for training, various alternatives are available. Training can be carried out using the individual pixels themselves as training samples. In this case one would follow with pixel-by-pixel classification. A more practical procedure, and one of the objectives of developing BLOB in the first place, is to train using the blob feature vectors

as training samples, and follow with blob classification. In blob classification we classify each blob according to its feature vector. Then we classify each pixel to the same class as the blob to which the pixel belongs, in order to produce a classification map. If we wish to make only a proportion estimate of each class we accumulate the total number of pixels in each blob belonging to each class, so that it is not necessary to process the individual pixels again.

Blob classification has the obvious advantage of data compression. It also carries whatever advantages or disadvantages may have accrued from the spatial preprocessing. To help understand what these may be we describe the algorithm in more detail in the next section.

3. DETAILS OF ALGORITHM

In the following paragraphs we describe the details of the BLOB algorithm and discuss its treatment of interior pixels, boundary pixels and small fields.

3.1 MATHEMATICAL DESCRIPTION

The clustering algorithm upon which BLOB is based was developed by A. P. Pentland [2]. The basic steps in clustering are as follows:

1. For each pixel decide which existing cluster it is closest to; the distance measure used is

$$d_i^2 = (x - \bar{x}_i)^T D_i^{-1} (x - \bar{x}_i) + \frac{n}{2} \ln |D_i|$$

where

x is a column vector of dimension n , the pixel vector

$\bar{x}_i$ is the sample mean of the pixels already included in an existing cluster, i .

D_i is a diagonal matrix of n sample variances of the pixels already included in an existing cluster, i .

2. If $d_i^2 > \tau$ for every existing cluster decide that the pixel belongs to none of the existing clusters, and start a new cluster with mean $\bar{x}_j = x$ and $D_j = \text{default}$.
3. Whenever a pixel is classified to cluster, i , update the statistics of this cluster by recursively computing the mean, $\bar{x}_i$, and the variances, D_i , including the current pixel.
4. A variety of procedures have been utilized to establish the initial clusters, including randomly selecting a number of pixels from the scene to form starting clusters, but usually the algorithm is run successfully with no seeding at all.

In the BLOB algorithm the distance measure, d^2 , is modified by including additional components relating to the spatial position of the pixel. We have in many cases found it satisfactory to use a fixed covariance matrix common to all of the clusters (i.e., the "blobs"), so that it is not necessary to update the variances or to include the $\ln |D_i|$ in the distance measure. In the simplest implementation the distance measure then becomes,

$$d_i^2 = w(x - \bar{x}_i)^T M^{-1} (x - \bar{x}_i) + \frac{(\ell - \bar{\ell}_i)^2}{v_\ell} + \frac{(p - \bar{p}_i)^2}{v_p}$$

where

- x is the spectral pixel vector
- ℓ is the pixel line number
- p is the pixel point number within the line
- M is a fixed n x n spectral covariance matrix
- $\bar{x}_i$ is the spectral mean of blob, i.
- $\bar{\ell}_i$ is the line mean of blob, i.
- $\bar{p}_i$ is the point mean of blob, i.
- w is a relative weight between the spectral and spatial contribution to distance.

Motivated by a desire to make the structure of the blobs match our notion of the East-West/North-South rectangular structure of the fields of an agricultural scene we have incorporated modifications and combinations of modifications of the spatial distance measure, as follows:

1. Line and point numbers are replaced by East and North coordinate values. (The mean positions of the blobs are then transformed back to line and point coordinates, for presentation to the user, for locating the position of the blob in imagery.)
2. Two additional varieties of spatial distance measure have been tried using these revised line and point coordinates, as follows:

$$a. \text{ spatial distance} = \sqrt{\frac{(\ell - \bar{\ell})^4}{V_{\ell}^2} + \frac{(p - \bar{p})^4}{V^2}}$$

$$b. \text{ spatial distance} = \max \left\{ \frac{(\ell - \bar{\ell})^2}{V_{\ell}}, \frac{(p - \bar{p})^2}{V_p} \right\}$$

Case a. produces spatial iso-distance contours which form "super-ellipses".
Case b. corresponds to spatial iso-distance contours which form rectangles.

Our experience is that these variations make no practical difference since the blobs tend to shoulder together to fill the space available along natural (spectral) boundaries in any case (see again Figure 1). Furthermore, in cases where a large naturally homogeneous area is broken into two or more blobs the shape of the boundary is determined by the process of sequentially adding pixels to blobs and updating the mean, rather than by the detailed form of the distance function (see the top central area of Figure 2 for an example case). In current practice* we use the transformation 1. above, and the maximum squared distance measure, 2.b. above. Also, in current practice, the spectral features which are used are the Tasselled Cap "brightness" and "green" features from one or several times; since these are nearly uncorrelated to one another only the diagonal terms of the covariance matrix are used.

*[NOTE: The current working version of BLOB has been completely revised and reprogrammed by W. Richardson, including in particular the introduction of the maximum squared distance measure, and including numerous techniques to speed up the calculation by a factor of 5 or 6. At present BLOB requires about 33 msec per pixel for 9 channel data running on ERIM's 7094 computer, or .5 msec per pixel on the University of Michigan's Amdahl 470/V computer, both times being comparable to conventional quadratic classification rules. Running time is not a strong function of the number of channels being used.]

3.2 BLOB TREATMENT OF INTERIOR PIXELS

The net effect of BLOB is to smooth out the identifications of within field pixels. Thus, if an isolated pixel in the middle of a field is spectrally somewhat different than its neighbors it will nevertheless be included with them in the same blob. If the pixel is much different, spectrally, than its neighbors it will be identified as a separate (one pixel) blob, or will be included with some nearby blob of similar spectral character. The net effect is to reduce the "salt and pepper" appearance of conventional classification maps, or of conventional spectral clustering maps without consideration of spatial information.

3.3 BLOB TREATMENT OF BOUNDARY PIXELS

It is informative to consider how BLOB processes mixed pixels at the boundary of two fields. In conventional classification such pixels may masquerade as a third class of material which may be located geographically some distance away in the scene. Figure 4 illustrates this idea. In Figure 4(a) a mixed pixel straddles a boundary between two classes, A and B. The signal "x" from this pixel is typical of the signals which would come from a Class C, and if no further information is given the pixel will be identified as Class C. In Figure 4(c) the joint density of signal and position are shown and it is clear that the pixel (x',d') will be classified as Class A or as Class B, but certainly not as Class C. (Pixels along boundaries will tend thus to be equally divided between the adjacent classes.)

Of course, if the Class C field is geographically nearby, then the pixel will still be misclassified, but such instances will be few in number.

3.4 BLOB BEHAVIOR FOR SMALL FIELDS

Consider the behavior of BLOB in case there are small fields, for example strip-fallow farming common in the northern Great Plains of the U.S. In this case blob 'A' may cover several wheat strips, and blob 'B' may cover several overlapping fallow strips. (This is possible because BLOB as presently implemented does not take any account of contiguity of classes -- only of nearness.) The positions of these blobs might be quite close together, and in particular the mean of A may fall in a fallow strip while the mean of B may fall in a wheat strip. In such cases it is almost certain that no pure pixels will be available for training, but it is still desirable to be able to visually inspect the coverage of each blob, to notice that it occurs in a strip fallow situation, etc. Improved methods of display are being developed but much remains to be done in this area.

As the size of fields gets smaller the number of blobs may increase until each blob is composed of a few isolated pixels which are spectrally alike; in other words, BLOB degenerates gradually to a pixel by pixel processor.

4. EVALUATION OF BLOB PERFORMANCE

Evaluation ought to imply a careful definition of measures of performance, of the algorithms being tested, and of the range of conditions of measurement. In this sense there has been no adequate evaluation of BLOB. BLOB is a heuristically evolving procedure, and testing has mainly been for the purpose of guiding our insight.

BLOB should be evaluated for performance in several areas: ease in extraction of training statistics; classification accuracy and/or proportion estimation accuracy; and data compression. We have adopted BLOB in large part because of the ease of training and the compression of data.

4.1 EXTRACTION OF GROUND TRUTH

In current practice blobs are labelled for training purposes by visual comparison between a ground truth map or image and a line printer blob map. Usually the line printer map is a map of stripped blobs, as in Figure 3. The blobs are numbered with a special modulo 50 symbol set. A second map keeps track of which set of 50 a given blob is in. Sometimes an auxiliary printout of unstripped blobs such as Figure 1 is used to make the visual association between image and line printer map easier. Even with such primitive arrangements the time to obtain wall to wall ground truth is significantly less than for previous competing methods.

4.2 DATA COMPRESSION

Data compression is particularly important because it allows us to concentrate on analyzing data dependencies over a wide range of ancillary conditions. Depending on the application, BLOB provides a data compression factor of 5-30. For example, suppose that 7-channel data are collected from a spacecraft multispectral scanner and that for certain applications, it appears suitable to blob with an on-board processor and transmit the blob mean spectrum for each blob and the blob identification number for each pixel. Suppose on average there are 30 pixels per blob. Then the average number of channels per pixel is $1 + 7/30$ for a net data compression of approximately 6.

Much of our current work is concerned with proportion estimation rather than the production of a class map, and with studies of the signatures of classes under various conditions. For these purposes the net compression factor is closer to 30, since only the blob spectral mean and the number of pixels per blob need be retained.

4.3 CLASSIFICATION/PROPORTION ESTIMATION

Qualitatively we do not expect the classification/proportion estimation performance of BLOB to be any worse than pixel-by-pixel classification; in fact because of its rational treatment of boundary pixels BLOB should perform better in these categories. However, to date, no valid comparative tests have been made of blob training, classification and proportion estimation vs. a conventional pixel-by-pixel classification approach. Such tests are planned for the immediate future.

5. SUMMARY

The BLOB algorithm as presently implemented is simple in concept and in execution. We believe that it exploits most of the spatial information available in agricultural scenes of Landsat MSS data. For other classes of scenes or for higher resolution data additional sophistication may be warranted, such as the inclusion of textural features in the pixel vector, or the addition of the capability to annex (join together) adjacent blobs of similar spectral character.

The algorithm has been discussed with respect to three main functions; training extraction, classification/proportion estimation and data compression. We believe it has significant value in the first and the last of those categories. For classification performance it appears no worse than pixel by pixel, but this is unproved.

The greatest potential for the technique remains to be exploited, namely its use in an interactive mini-computer environment. We can envision training pixels being extracted from complex scenes, for example marshland or forest, merely by the analyst indicating a single pixel. The display then would present for inspection the entire blob to which that pixel belongs. The computer could further cluster blobs spectrally and the analyst could indicate which blobs to merge into the same class.

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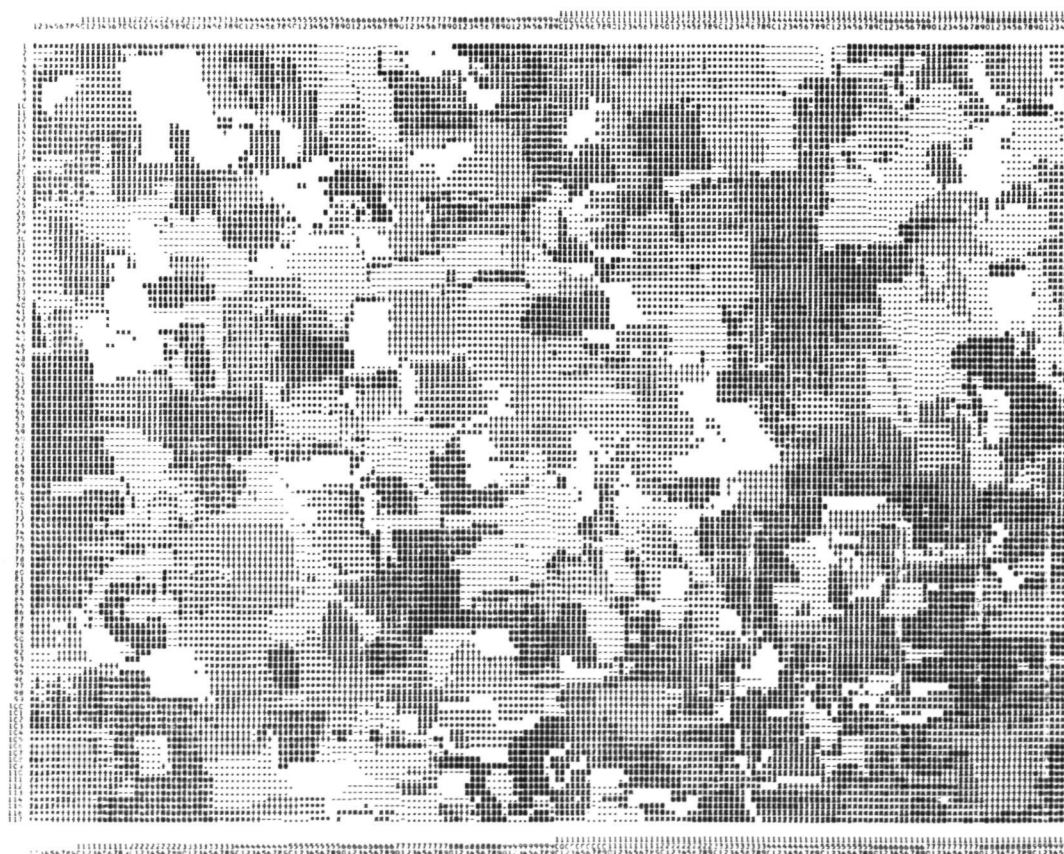


FIGURE 1. MULTITEMPORAL-SPECTRAL-SPATIAL BLOB MAP OF A 5 x 6 SEGMENT IN KANSAS. The dates used for blobbing are 7 Nov 75, 6 May 76, 1 Jun 76.

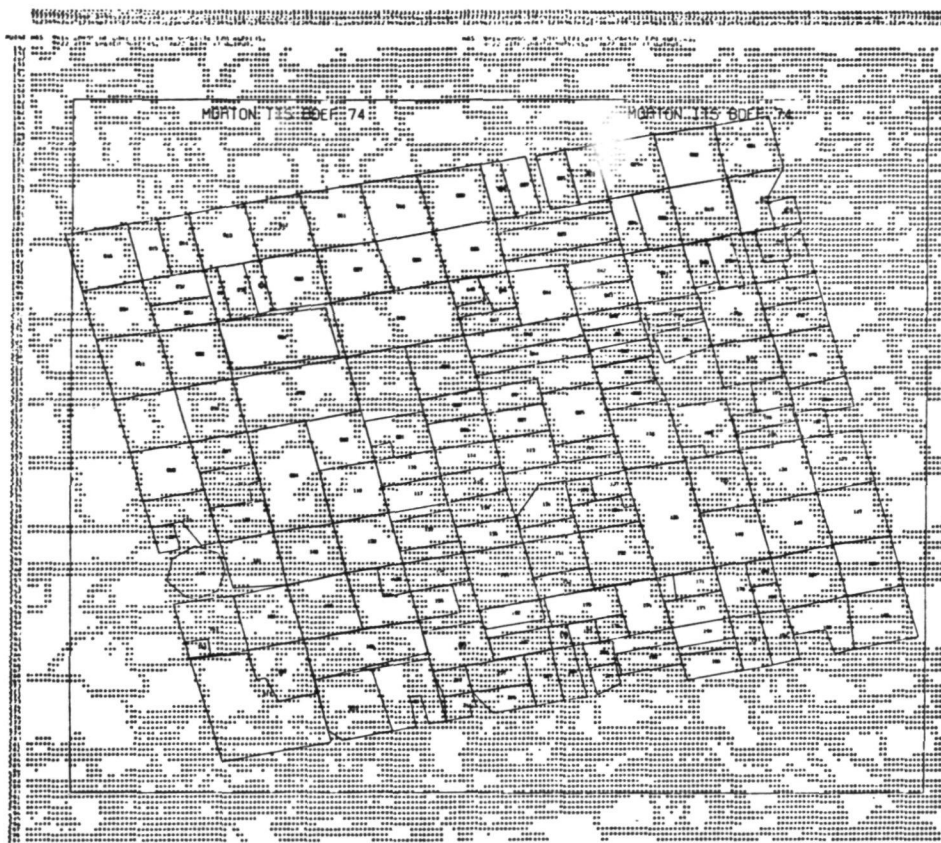


FIGURE 2. MORTON ITS MULTITEMPORAL SPECTRAL SPATIAL BLOB MAP

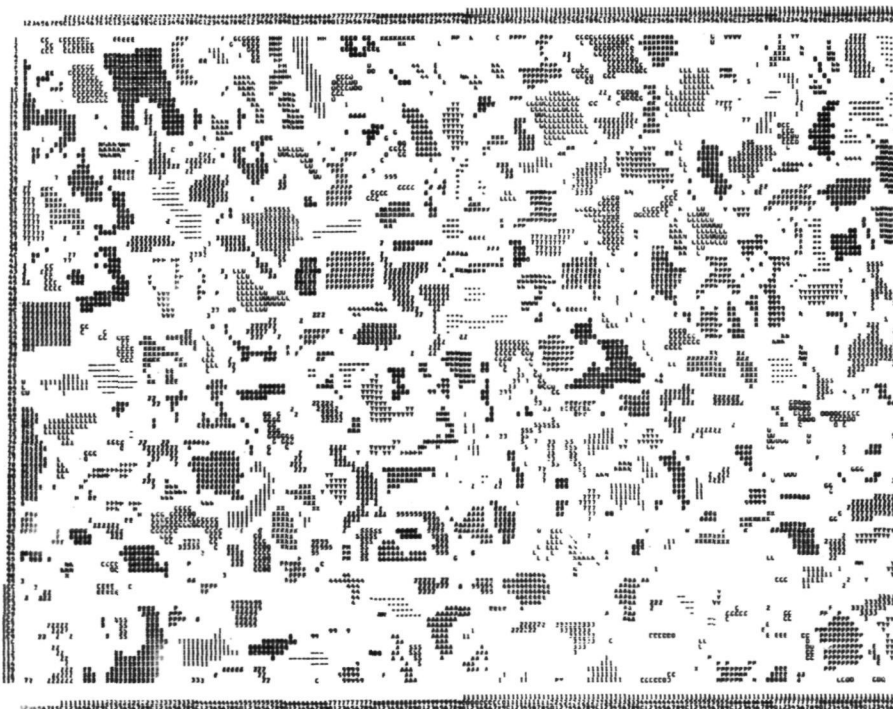


FIGURE 3. EXAMPLE OF STRIPPED BLOB MAP. Identical to map of Figure 1, except that pixels on boundary between blobs have been changed.

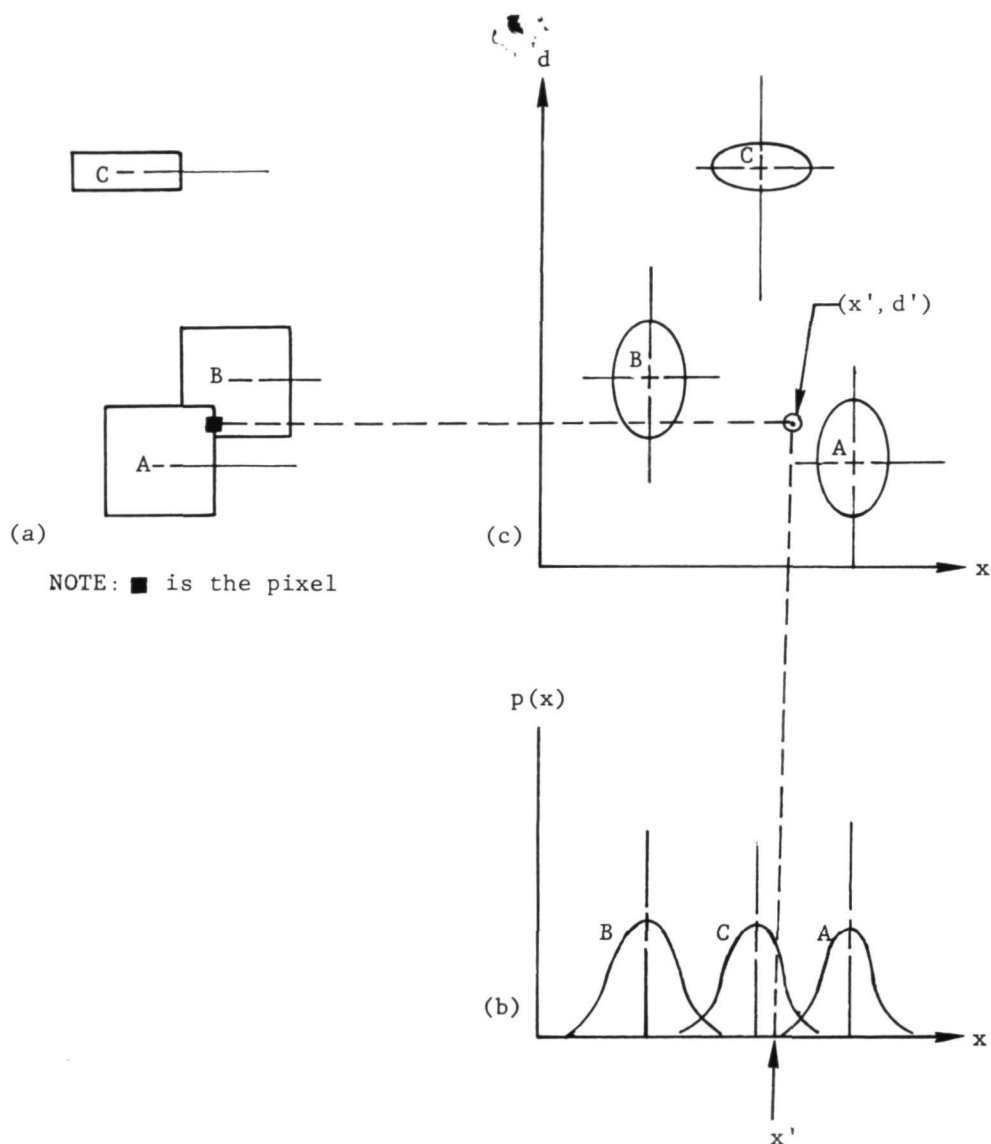


FIGURE 4. ILLUSTRATION OF BLOB TREATMENT OF BOUNDARY PIXELS

- (a) Shows a pixel on the boundary of fields of classes A and B, with the nearest field of class C some distance away.
- (b) Hypothetical probability density functions of the classes A, B, and C, with the pixel value, x' , falling between A,B and in the range of class C.
- (c) The hypothetical joint probability density of (vertical) distance, d , and pixel value, x . The pixel in question is represented by the point (x', d') .

MULTISPECTRAL SYSTEM ANALYSIS THROUGH MODELING AND SIMULATION*

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ABSTRACT

The design and development of multispectral remote sensor systems and associated information extraction techniques should be optimized under the physical and economic constraints encountered and yet be effective over a wide range of scene and environmental conditions. Direct measurement of the full range of conditions to be encountered can be difficult, time consuming, and costly. Simulation of multispectral data by modeling scene, atmosphere, sensor, and data classifier characteristics is set forth as a viable alternative, particularly when coupled with limited sets of empirical measurements. A multispectral system modeling capability is described. Use of the model is illustrated for several applications -- interpretation of remotely sensed data from agricultural and forest scenes, evaluating atmospheric effects in Landsat data, examining system design and operational configuration, and development of information extraction techniques.

INTRODUCTION

Remotely sensed, multispectral scanner (MSS) data have been shown to be of value in a variety of applications related to earth resources surveys. The design and development of future scanner systems and related information extraction algorithms must be optimized under a variety of both physical and economic constraints to yield maximum amounts of information at a minimum cost for a particular application or a series of applications. In addition, optimal information extraction algorithms must be developed to utilize present scanner systems (e.g., Landsat) for applications of current interest. Such optimal development is extremely difficult, however, due to the wide range of parameters available to the scanner system designer, the wide range of scene characteristics of interest in a particular application, and the wide range of atmospheric conditions which may be encountered in an operational environment.

APPROACH

A viable approach to these difficult design and development problems is to simulate MSS data based on theoretical models of scene, atmospheric, scanner system, and data processor characteristics. Employing realistic measurements of the parameters required by these models, data can be generated at a relatively small expense over a wide range of conditions of interest. These data can then be analyzed for the purposes mentioned above. Simulated data can also be used to supplement empirical data obtained by an experimental or operational sensor system, to facilitate a greater understanding of those data.

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A Multispectral System Simulation Model has been developed at ERIM, based on previously developed capabilities for mathematically modeling the physical processes involved in the generation of remotely sensed signals. Outputs from the model have been employed for a variety of applications, some of which are illustrated later in the paper.

DESCRIPTION OF MODEL

The present basic components of the ERIM Multispectral System Simulation Model are:

- (a) bidirectional reflectance model,
- (b) atmospheric radiative transfer model,
- (c) sensor system model, and
- (d) data processor model.

An overall block diagram of the model is presented in Figure 1. The basic equation used to compute the spectral radiance L_λ observed by the scanner is:

$$L_\lambda = L_\lambda(S)\tau(\lambda) + L_\lambda(P)$$

where λ is wavelength,

$\tau(\lambda)$ is the spectral transmittance of the atmosphere along the path between surface and sensor,

$L_\lambda(P)$ is the spectral path radiance due to multiple scattering by the atmosphere along the path, and

$L_\lambda(S)$ is the spectral radiance emanating from the surface, i.e., the radiance before any atmospheric effects occur.

The surface radiance, in turn, depends on the direction and magnitude of irradiance at the surface, the scene bidirectional and diffuse reflectances, and the direction of observation. Specifically, the surface spectral radiance is:

$$L_\lambda(S, \theta_v, \psi_v, \theta_s, \psi_s) = \frac{1}{\pi} E_\lambda(\text{Direct}, \theta_s, \psi_s) \cdot \rho(\text{Bidirect}, \lambda, \theta_v, \psi_v, \theta_s, \psi_s) + E_\lambda(\text{Diffuse}) \cdot \rho(\text{Diffuse}, \lambda)$$

where $E_\lambda(\text{Direct})$ is the direct (solar) spectral irradiance,

$E_\lambda(\text{Diffuse})$ is the diffuse or hemispherical (sky) spectral irradiance,

$\rho(\text{Bidirect}, \lambda)$ is the bidirectional spectral reflectance of the surface, relative to that of a horizontal, perfectly Lambertian surface,

$\rho(\text{Diffuse}, \lambda)$ is the Lambertian spectral reflectance of the surface (i.e., response to a diffuse radiation source),

and (θ_v, ψ_v) and (θ_s, ψ_s) are the zenith and azimuth angles of view and sun, respectively.

Both the irradiance terms and the terms L_p and T depend on the properties of the atmosphere for the condition under consideration. In addition, E_{Diffuse} and L_p depend on the albedo ρ_B of the background surrounding the surface element being viewed.

The bidirectional reflectance model used is that developed by Dr. G. H. Suits of ERIM [1,2]. This model computes the bidirectional reflectance of a vegetative canopy as a function of the spectral reflectance and transmittance characteristics of each of several canopy components and their sizes and average orientations within the canopy (i.e., horizontal and vertical projections of their cross-sectional areas). The basic model assumes that the canopy is infinite in extent and that its components are randomly oriented in layers. Computed values have agreed well with measured values in several instances [3-7]. Exceptions have been noted for row crops by two investigators [5,6]. Verhoef and Bunnik incorporated a crop row-effect parameter in a one-layer Suits' model and reported improved agreement between subsequently calculated and measured values [6]. In both References 6 and 7, certain discrepancies between modeled and measured reflectances have been attributed to specular leaf reflectances. Suits believes they could be a consequence of his use of only vertical and horizontal elements to represent leaf distributions and is developing a simple modification of his model to overcome this problem. Recently, Suits has added slope and aspect (i.e., azimuthal direction of slope) parameters to enable prediction of reflectances from canopies on sloping terrain (an example is presented later).

In the event that empirical measurement data are available, such as laboratory or field-measured reflectance spectra, these spectra can be utilized in simulation calculations in place of spectra computed theoretically with the reflectance model. Similarly, measured radiance spectra can be inserted at the appropriate place in the chain of calculations.

The atmospheric radiative transfer model is that developed by Dr. R. E. Turner of ERIM [8,9]. This model effectively has two parts, one which computes direct and diffuse solar irradiance spectra on a surface (at sea level or at any specified altitude), and the other which computes the spectral path radiance and spectral transmittance of the atmosphere along the path between the surface of interest and the sensor. These computed spectral quantities all depend on the state of the atmosphere and some depend also on sun position, view geometry, and/or background surface, as noted earlier. The diffuse irradiance term computed by the model includes all radiation scattered at least once by the atmosphere. Usually, this radiation has been assumed to be uniformly distributed throughout the hemisphere; however, it would be more accurate to take into account its actual spatial distribution which is concentrated in the aureole which surrounds the sun. The model assumes multiple scattering in a plane-parallel atmosphere. Absorption by aerosols can be included in the computation, although it usually has been omitted in calculations made. The most direct way to describe an atmospheric state for the model calculations is to input measured atmospheric optical thickness readings. Alternatively, one can utilize standardized atmospheric states which are labeled by their horizontal visual ranges.

The major component of the sensor system model is the set of functions that represent the relative spectral responses of the scanner's spectral channels. In the model, these can have arbitrary shapes as a function of wavelength. A radiance responsivity calibration option exists to convert effective inband radiances to sensor output units, and a sensor noise option is planned. For studies of satellite system operational considerations, an orbital model and sun position model permit one to predict system responses for a variety of orbit inclinations, equatorial crossing times, and scanning configurations.

Multispectral data classifier performance is simulated through a Monte Carlo technique based on statistics determined for the spectral classes of interest. Random samples are drawn from multiple scene-class populations and classified

into specified recognition classes using statistical decision rules. In addition to pure single-class pixels, multiclass mixture pixels which include field boundaries and/or spatial misregistration can be simulated [10].

APPLICATIONS OF MODEL

The multispectral system simulation capability described above has proven to be useful for a number of applications. Several representative uses are illustrated and described in this section, beginning with agricultural applications.

Knowledge of the effects of various factors on crop reflectance and their relative importance are both important in the design and development of processing techniques and procedures for crop inventory. Winter wheat is a crop that has a rather distinctive temporal development pattern relative to other crops and natural vegetation in the U.S. Great Plains. Wheat reflectance as a function of time was simulated using the model and field-measured wheat canopy component characteristics [11]. Seven growth stages, from emergence through harvest, were simulated (see Table I).

TABLE I. WHEAT GROWTH STAGES SIMULATED

<u>Stage Number</u>	<u>Simulated Date</u>	<u>Wheat Growth Stage</u>	<u>Percent Growth Cover (Medium Density)</u>
1	Mid November	Emergent	14
2	Mid April	Jointing	44
3	Mid May	Pre-heading	79
4	End May	Post-heading	82
5	Early June	Senescing	64
6	Late June	Ripe	60
7	Early July	Harvested	14

The sun position was chosen to match that at Landsat overpass time on each date at 38°N latitude. Atmospheric effects and Landsat inband radiances then were computed for several different atmospheric states. The resulting time tracks of wheat radiance in Landsat Bands 5 and 6 are presented in Figure 2 for one atmospheric state.

The family of plots in Figure 2 illustrates that wheat reflectance depends substantially on two canopy parameters -- density of vegetation, which differs from column to column in the array of plots, and soil brightness, which differs from row to row. The sparse, medium, and dense labels of canopy density apply on a relative basis at any given stage of development -- on an absolute basis, the dense canopy at emergence or post harvest had a lower percentage ground cover than did the sparse canopy at the time of full canopy development (i.e., at heading). Shadowing of exposed soil by the wheat leaves is another factor affecting the canopy reflectance. As one would expect, the soil brightness affected the total radiance most when ground cover percentage was lowest -- these and other simulated values serve to quantify the magnitude of the effect and indicate the variety of signature time tracks that are possible.

A related parametric study examined in more detail the characteristics of wheat reflectance during the "greening up" stages of wheat development [12]. Again, Landsat inband values were computed and analyzed. More levels of canopy

density were included through a parameter GLAI (Green Leaf Area Index) which is the total single-sided surface area of green leaves per unit area of ground. Figure 3 presents a family of curves for which GLAI varies from 0 (bare soil) to 26 (an extremely dense value to serve as a limiting case) with the mean soil brightness; typically mature wheat GLAIs are on the order of two to four, occasionally as high as six or eight. If GLAI were fixed, the percent ground cover and canopy reflectance could both vary, depending on the structure of the canopy. Canopy structure in the Suits model is implicit in the ratio of vertical to horizontal leaf area projections (V/H ratio) which also can be thought of as defining an average effective leaf orientation. The effect of varied V/H ratio is also displayed in Figure 3. (The actual V/H ratio of a wheat field will change throughout its development cycle.)

Families of curves for light, medium, and dark soil brightnesses are superimposed in Figure 4. For sparse canopies, the soil brightness is the predominant factor, while for dense canopies the V/H ratio predominates. Relatively small changes in reflectance occur when GLAI increases beyond a value of two. Alternative displays of the data in Figure 4 suggested that a polar coordinate description of the data would tend to decouple the effects of soil brightness and canopy density. Specifically, in Landsat reflectance space, an increase in soil brightness causes an increase in the radial component, while an increase in GLAI can be correlated with a counterclockwise rotation of a radial line through the origin. This rotation is both strikingly independent of soil brightness and not too sensitive to V/H changes. For Landsat signal space, a similar result is predicted but with a displacement of the origin of rotation due to path radiance effects. The polar angle for Figure 4 would be the angle whose tangent is the ratio of Band 7 to Band 5 reflectance, a quantity that has been found useful in Landsat analyses as a green vegetation indicator [e.g., 13-15].

The results presented here explain the reasons for the success of the 7/5 ratio and derivatives thereof and suggest that the polar angle, or a "green angle" measured from the radial line of bare soil, might provide a more linear measure of green vegetation density. Rather than utilizing just two of the four Landsat bands for defining the angular and radial components, linear combinations of all four such as those of the tasseled cap transformation [16] are recommended. The green angle is most closely related to the green component of the tasseled cap transformation.

The development of the tasseled cap transformation was based on calculations made using the Suits model, as well as analysis of empirical Landsat data. The majority of variance in Landsat data lies in the plane defined by the brightness and green axes. This transformation has proven to be a useful data processing technique and interpretation aid.

The above calculated reflectance values compared favorably with empirical values measured with a Landsat-band radiometer in wheat fields throughout a Kansas growing season, as shown in Figure 5.

Forests are frequently found in mountainous or hilly regions on sloping terrain. Slope and aspect do have pronounced effects on remotely sensed data. The slope and aspect parameters of the Suits model were used to predict the reflectance of a pine forest under various slope and aspect conditions. Figure 6 presents one set of results for Landsat Band 6 which indicated the extent to which the reflectance of a pine canopy is predicted to depart from that of a Lambertian (perfectly diffuse) surface.

Atmospheric effects are present in remotely sensed data acquired for all applications. An understanding of the magnitude and character of these effects is important to both the interpretation of data and the development of information extraction techniques and procedures. Figure 7 (reproduced from Reference 17) illustrates several facts about Landsat Band 4 data. First, path radiance

constitutes a large fraction of the signal from a target of medium reflectance ($\sim 8\%$). Second, the amount of atmospheric haze (indicated by horizontal visual range) affects the signal received. Finally, there are appreciable scan-angle-dependent effects even over the limited $\pm 6^\circ$ scan range of the Landsat MSS. Calculations of atmospheric effects can be tailored to the particular conditions and parameter values appropriate for any given application study.

The system model also has been used to examine the influence of scan geometry and system orbit parameters and sensor spectral characteristics on scanner responses [18]. In addition to atmospheric effects, the question of surface glint effects was addressed. Figure 8 presents a map of orbital coverage from 70°N to 70°S latitude along a ground track simulating the Thematic Mapper on an earlier proposed orbit with an 11:00 AM equator crossing. The cross-hatched zones indicate the surface slopes for which direct specular glint conditions could exist (e.g., from the sea surface) as a function of satellite latitude. By way of explanation, surface areas in the zone labeled $\geq 15^\circ$ would be susceptible to glint from any surface slope of 15° or greater; the enclosed zones for $\geq 10^\circ$ and $\geq 5^\circ$ would be included as well in the potential glint region. The predicted glint potential for the currently planned 9:30 AM Thematic Mapper orbit is much less, with surface slopes of at least 20° being required and the $\geq 20^\circ$ zone roughly matching the $\geq 10^\circ$ zone of Figure 8.

Figure 9 presents the nominal spectral bands of Thematic Mapper and Landsat MSS along with a reflectance spectrum of a green leaf to indicate the potential utility of the model in addressing problems of sensor spectral band selection. These problems require a consideration of atmospheric and viewing conditions and effects in addition to the spectral characteristics of scene surfaces.

Data processor simulation, based on signature statistics, is exemplified by previously reported predictions and analysis of the effects of spatial misregistration on classification performance [9].

SUMMARY

The ERIM Multispectral System Simulation Model has been described and several illustrative applications have been presented which address agricultural, forestry, general Landsat data interpretation and analysis, and system parameter selection problems. The capabilities described represent one implementation of a class of physical models which can play an important role in the continued development of remote sensing technology, especially when coupled with appropriate empirical measurements. The full potential of such modeling is yet to be realized.

ACKNOWLEDGEMENTS

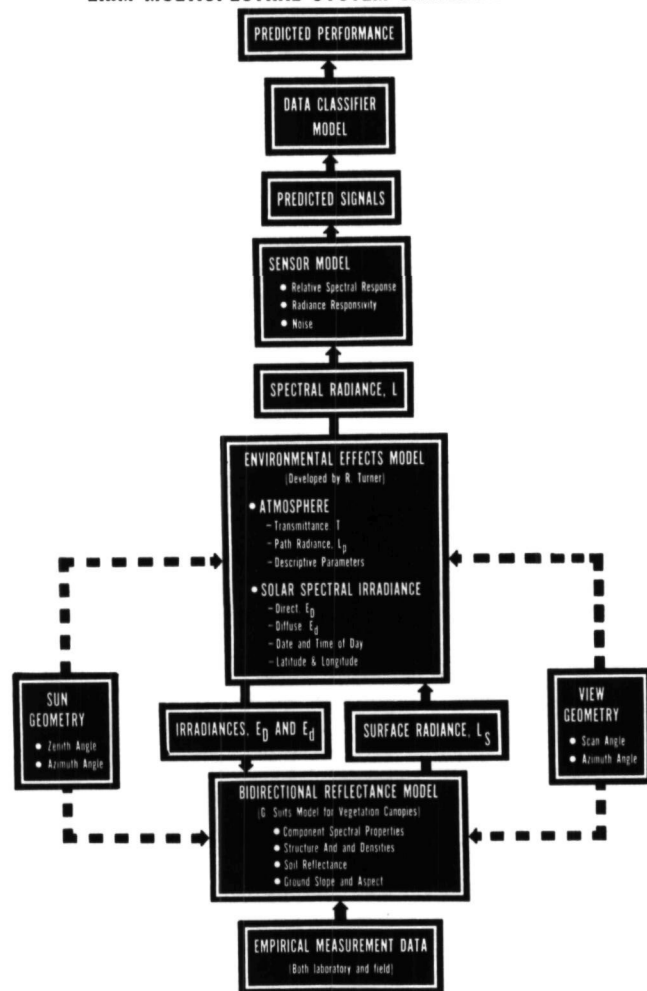
The authors acknowledge the financial support of NASA and the technical support and consultation of other ERIM personnel, including R. F. Nalepka, R. J. Kauth, G. H. Suits, and R. E. Turner.

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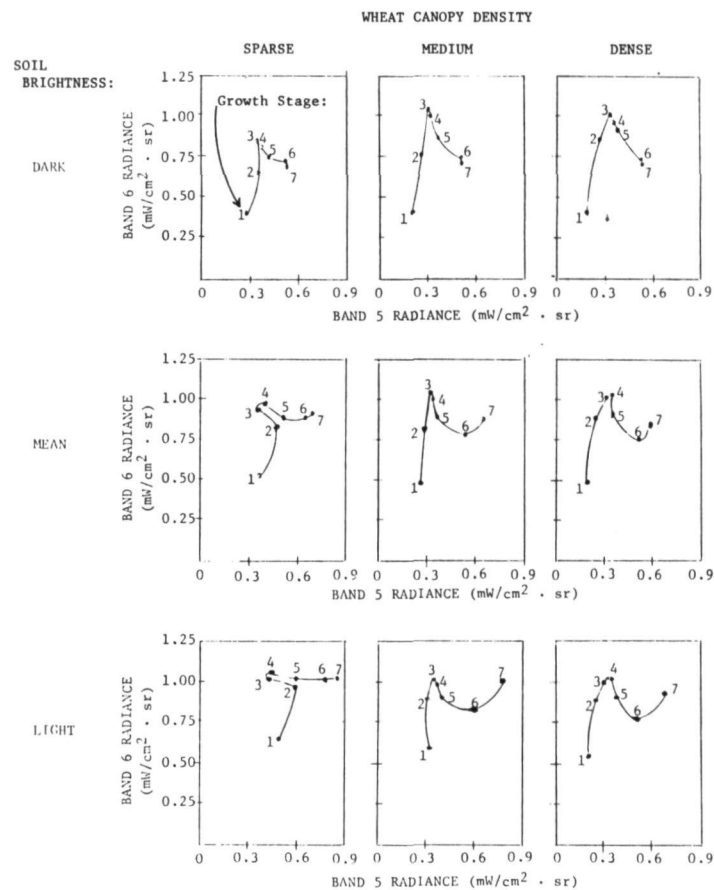
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FIGURE 1
ERIM MULTISPECTRAL SYSTEM SIMULATION MODEL



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FIGURE 2
TEMPORAL TRACKS OF SIMULATED WHEAT CANOPY
RADIANCE SIGNATURES IN LANDSAT BANDS
(Key to growth stages is in Table I).



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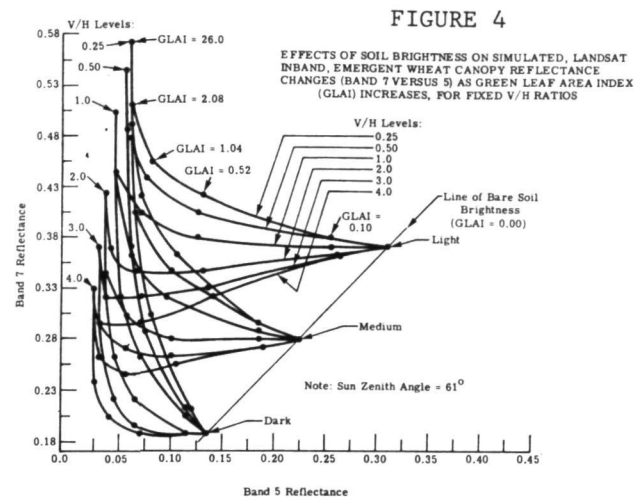
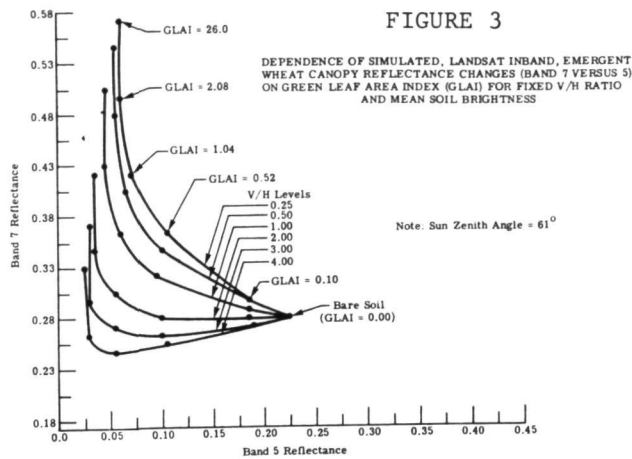


FIGURE 5

Comparison of Simulated and Empirical Reflectance Data

Simulated

Measured

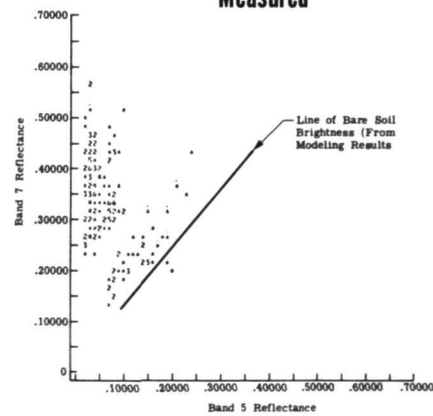
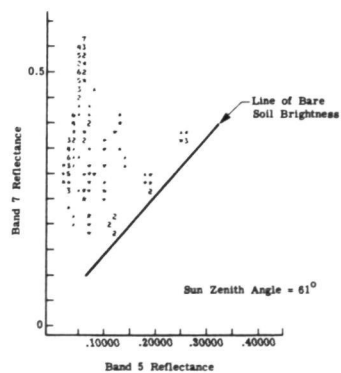


FIGURE 6
**Interpretation of Data
From Forested Areas**

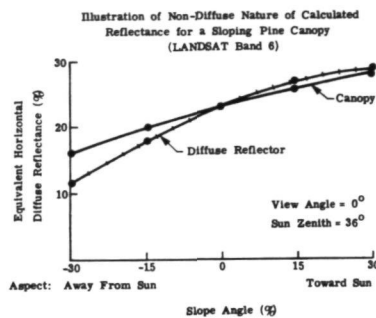


FIGURE 7
**Prediction of Atmospheric Effects
in LANDSAT Data**

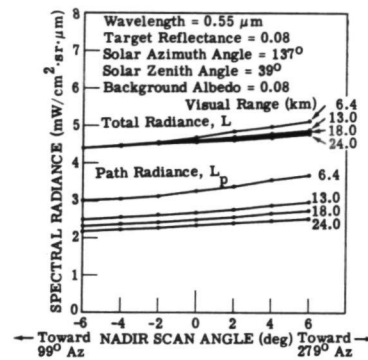


FIGURE 8
Sensor Orbit Selection

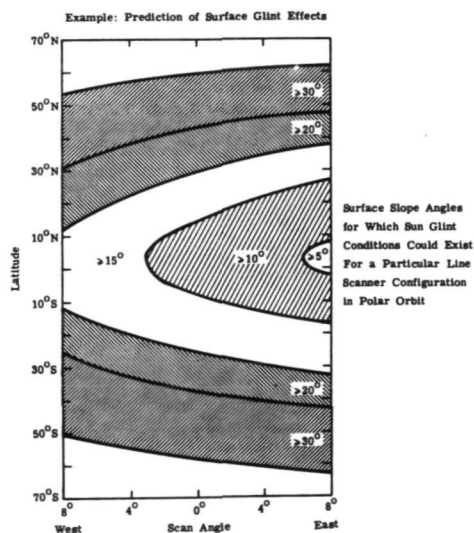
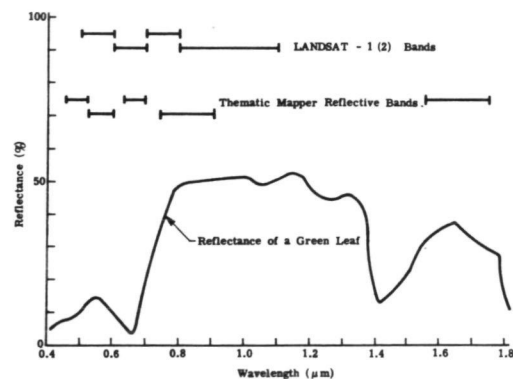


FIGURE 9
Sensor Spectral Band Selection



A 'DIGITAL' TECHNIQUE FOR
MANUAL EXTRACTION OF DATA FROM AERIAL PHOTOGRAPHY

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ABSTRACT

There is a growing need among local and regional planning and resource management agencies for accurate land use/land cover data. Usually, these data must be to a stringent level of detail and precision, and in a format compatible with simple computer storage or existing models. In addition, the data have to be provided within budgetary and time constraints. This paper describes an interpretation technique developed to meet these requirements.

ERIM's experience in the interpretation of remote sensing data has established that a cell or point format is a highly efficient method of interpretation when a fine spatial resolution is required and/or the number of classes to be interpreted is large. Applying this 'digital' format to the manual interpretation of aerial photography allows full utilization of the superior capabilities of a human interpreter to discriminate and identify the detailed surface and cultural features necessary for many planning and management activities.

The interpretation procedure described uses a grid cell approach. In addition, a random point is located in each cell. The procedure required that the cell/point grid be established on a base map, and identical grids be made to precisely match the scale of the photographic frames. The grid is then positioned on the photography by visual alignment to obvious features. Several alignments on one frame are sometimes required to make a precise match of all points to be interpreted. This system inherently corrects for distortions in the photography, which are often a major source of error in photographic data extraction. Interpretation is then done cell by cell. In order to meet the time constraints, first order interpretation should be maintained. The data is put onto coding forms, along with other appropriate data, if desired.

This 'digital' manual interpretation technique has proven to be efficient, and time and cost effective, while meeting strict requirements for data format and accuracy. The technique is applicable to many situations where extraction of detailed information from remote sensing imagery is required.

1. BACKGROUND

The Environmental Research Institute of Michigan was asked to prepare accurate land use/cover data from remote sensing imagery as input to the

Toledo Metropolitan Area Council of Government's section 208 area-wide water management program. Within time and budget constraints, data was needed in a format and level of precision required to input an existing water quality model. This model requires information on a specific point basis, that is, the land cover/use at a set of specific locations throughout a given watershed. Information on other pertinent factors, such as soils and topography, is also collected for these points, which are addressed using a readily determinable earth coordinate system, in this case, the Universal Transverse Mercator grid. The result constitutes a Systematic Unaligned Sample (one point randomly placed within each cell of a uniform grid), which has been shown to be a preferred system for sampling heterogeneous features with unknown, but uneven areal distribution (1,2).

The technique described here was developed and applied to medium scale color infrared aerial photography whose date of acquisition coincided with water quality sampling data. Thirty-five categories of land use/cover, and 12 associated features, were included in the classification scheme. The data was recorded on pre-printed sheets, which were also used for recording other information such as soils, topography, watersheds, etc. It was then punched directly into disc storage, where it was available for statistical analysis, manipulation, and mapping. Field checking showed that the data exceeded 90% overall classification accuracy.

2. INFORMATION EXTRACTION PROCESS

The information extraction process covers the interpretation of the aerial photography to obtain land cover/use information for each cell/point. It includes preliminary set-up of maps and photographs, grid alignment and retrieval, interpretation and coding of data.

A. Preliminary Set-Up

The first order of business after receipt of the aerial photography is determination of scale, so that the appropriate cell/point grids can be produced. The scale of the first and last frames of each flight line is determined, using the base maps. Up to 6 frames within each flight line are also scaled, depending on the flight line length. The measurements are recorded separately for east/west and north/south directions, and then plotted sequentially along the flight line.

A plot of the frequency of the various scale factors indicates the scale range of the grids to be produced. For instance, for nominally 1:50,000 scale imagery, a grouping may be found around 1:51,000, with clusters toward the tails of the entire range, 1:49,000 and 1:53,000. Accordingly, a series of different grid scales are produced, spaced over this range. A representative example is shown below:

TABLE 1

52,632	51,020	49,603
52,137	50,556	49,020
51,600	50,000	

Multiple copies of the grids for the base maps must also be prepared, at the proper scale. The USGS 1:24,000 or 1:62,500 topographic quadrangles are one of the more appropriate base map series.

B. Grid Alignment

The first step in actual interpretation is alignment of grids on the photography. This is a time consuming and at times tedious job, but it is critical to the success of the interpretation effort. Two major procedures have been used, but each interpreter will develop his own technique for making an optimum fit as rapidly as possible.

Grid alignment consists of positioning a properly scaled cell/point grid over a photographic frame, or part of a frame, so that it corresponds precisely with the positioning of the cell/points as indicated on the base map. This correspondence is determined visually by examination of the same features on both the map and photography, and their relation to the cell/point grid. Such features as roads and road intersections, buildings, streams, and railroads are commonly used. In some cases, more indefinite features such as forest/field boundaries and lake shores can be used, but great care has to be exercised to be sure that changes in these have not occurred between the date of the map and the collection of the photography.

Since scale is seldom, if ever, constant across an entire frame of aerial photography, it is usually necessary to make several alignments, or grid sets, in order to completely cover an entire frame, with only a small area being "matched" and thus interpreted for each. This variation can be caused by topographic changes on the ground, changes in plane altitude and tilt, or a combination of these. In some cases, it can be necessary to use two or more different scale grids on the same frame, and to match only a very small area at a time. Topographic differences, because they are localized, can also cause only one or two points to be mislocated, while the surrounding area matches the map. This distortion, which is a function of the geometry of aerial photography, cannot be avoided. In varied terrain it can be a severe hindrance.

One way to avoid the distortion problem would be to use orthophotography. However, the time and expense required to produce the orthophotos from the original imagery negates one of the major benefits of the technique described in this paper -- being able to use standard, uncorrected aerial photos to gather precise land resource data in a real-time manner.

The general technique of alignment is as follows:

1. Select a grid or grids at an appropriate scale, based upon the scale determinations, or the scale of a previous frame in the flight line.
2. Try to match the grid over a large area, using two east/west running roads, then two north/south roads. This will quickly indicate which grid approximates the actual scale most closely, and will show scale distortions over affected parts of the photograph.
3. Using features which are readily identified, line up the grid in one direction, and then the other, by setting the features in their proper place. Try to include as great an area as possible, but without sacrificing precise alignment.
4. When the grid seems aligned for major features, rapidly scan each row and column for correspondence between the map and photograph. If the match is good, tape the grid on the photograph, and delineate with a grease pencil the limits to be interpreted (that area over which the grid is precisely aligned) for that grid set.
5. Prepare the retrieval sheets.

An alternative technique preferred by some interpreters is to identify a number of points which fell on identifiable features on the map, circle these on the grid overlay, and then position the grid until all these points corresponded with the proper features on the photograph. All of the rows and columns still need to be checked for precise positioning.

Using these techniques, the grids can be fairly rapidly aligned on a photograph, even when the scale changes across it. A quality criterion is required such that no point on the photographs is more than one of its diameters away from its location on the map, or a realignment or new grid set is required. Still, the decision of how well the grid "fits" any section of a frame is a subjective one made by the interpreter, and great care must be exercised to avoid sloppiness. In order to reduce some of this subjectiveness, it is recommended that every alignment made be reviewed by at least one other interpreter. This

interaction between interpreters brings about more precise alignments, and will catch some obvious misalignments before interpretation begins.

Since the magnitude of scale distortions increases geometrically away from the center of a photograph, alignment and interpretation of areas near the edges of the frames should be avoided. Standard 60% forward overlap (along the flight line) between frames, and 20% sidelap (between adjacent flight lines), facilitates this. In addition, the overlap enables the interpreters to make minimal use of badly tilted frames, or to avoid using them altogether. It also enables them to interpret areas covered by clouds on one frame, since in most cases the area will not be covered on the next or an adjacent photograph.

Two procedures with respect to alignment and interpretation may be followed. One is alignment of a single grid set, followed by immediate interpretation. This sequential mode is somewhat more inefficient than the second, however, especially where many grid sets, each covering a small area, are required. The second mode is to make all the alignments for a set of frames at one time, and then go back and do the interpretation. This system allows the interpreter to concentrate on one job at a time, either alignment or interpretation, and increased his proficiency and efficiency at each. It also eliminates waiting time by the coder since he is only needed during interpretation. Problems can arise, however, in that grids sometimes shift during the period between alignment and interpretation, necessitating realignment using the retrieval sheet. Also, photointerpreters should not spend much more than an hour consecutively doing the interpretation because of eye strain, and the alignment procedure affords a good break. A combination of the two modes of operation will afford a balance between the efficiency of aligning many areas at once, and the limitations imposed by sensible precautions for the welfare of the interpreters. It can also make allowances for personnel availability and external scheduling impacts.

In summary, some of the critical points to note concerning grid alignment are listed below.

1. Be sure the grid is properly positioned on the map, according to the geo-coordinates, with north up, and right reading.
2. Be sure the grid overlayed on the photograph is right reading, with north in the proper direction. Failure to do this can make alignment very frustrating.
3. Use the proper scale grid. Determination of the proper scale grid or grids, by alignment between east/west and north/south roads which are far apart, is critical (count the number of cells between roads, on the map and then the photograph). An improper scale grid can at times be forced into alignment over a small area. This should be avoided.
4. Try to cover as much area as possible with one grid set, but be aware of distortions and don't force the alignment. Stay away from the edges of the frame. Go to the adjacent frame instead.
5. Scan every row and column in the area being aligned, not just a few points or main features.
6. Don't worry about alignment outside of the area which will be interpreted for any one grid set.
7. Have another person review each alignment.

C. Retrieval

Because it may be important to be able to reexamine the land cover/use at a specific point, and if the use of future imagery to update the information is anticipated, it is necessary to document the precise positioning of the cell/point grids on the photography. This can be accomplished through a

retrieval process performed by the photointerpreters after each grid alignment is made.

The retrieval documentation consists of two sheets attached to each frame of photography used. One is a clear mylar, on which the fiducial marks of the photograph, and the corners of a region for each alignment have been pricked with a pin. The other is a paper copy of the cell/point grids on which the area interpreted for each grid set is noted, along with the grid scale used, and the region number. Figures 1 and 2 show examples of these sheets. These two sheets should be considered as an integral part of the photographic record.

Preparation of these retrieval sheets is as follows.

1. After a grid is aligned for a given area, the clear acetate is overlaid and taped down. It is given a north arrow and marked with the photo frame number.
2. The fiducial marks of the photograph are pricked in the acetate and circled.
3. The corners of a fixed region on the grid are then pricked on the acetate, and identified with the grid set number.
4. On the paper grid, the actual area interpreted for the grid set is inclusively marked with cross-hatchings, and the grid set number and grid scale used are noted.
5. For subsequent alignments on the same frame, the fiducial pricks in the acetate are realigned with the fiducial marks on the photograph, and a new set of pricks made and numbered for the new grid set. The area interpreted is delineated on the paper sheet in the same manner.

A standard procedure should be established governing the retrieval system. The region corners pricked on the retrieval sheet should be the same for all grid sets. Standard notations should be used. The paper sheet and a map should also be consulted when using the retrieval sheets to be sure that the area of interest has been properly identified.

Use of the retrieval sheets to realign the cell/point grid is simple.

1. Identify from the paper retrieval sheet the grid set in which the area of interest lies and note the grid scale used.
2. On a cell/point grid of the proper scale, align the pin-pricks for the desired grid set with the corners of the region used and tape the mylar to the grid.
3. Put the photograph under the grid and align the fiducial pricks in the mylar with the fiducial marks of the image.
4. Tape the aligned grid to the photograph. The retrieval sheet can then be removed for easier viewing.
5. Delineate with a grease pencil the area interpreted for this grid set.

Mylar, or some other stable transparent film should be used for retrieval sheets. This will minimize the differential expansion between the sheet and the imagery, which can make re-alignment difficult, and less precise.

The paper retrieval sheets attached to the photographs will also serve as an index to the interpreted areas on each frame, and help save valuable time in determining which image was used to interpret a given area of interest.

D. Coding

Computer generated coding forms are a simple data recording medium for the photointerpretation effort, as well as other data such as soils, topography,

watershed, etc. which may be gathered. These forms can be conveniently generated as listings by row and column of all the points in a region, with the geo-coordinates and I.D. numbers already assigned.

The coders need to be both thorough, in order to avoid errors, and able to write rapidly and neatly. The interpreters often can proceed much faster than a coder can write down the data, and it may take a while to get the two in synchronization and operating efficiently.

E. Interpretation

Interpretation should be done from the best available imagery with regard to clarity and contrast. Enlargements are not necessary. For many projects, the interpreters will need only a 10x hand magnifier to view the film. This magnification optimized the detail visible on an image, without bringing out the grain of most film. In some cases, especially urban areas, 8x magnifying stereo viewers will afford better interpretation through the added third dimension.

Decisions on the classification type for a cell are generally made based upon the dominant class within the cell. Thus, if 50% or more of a cell is one class, it is coded as that class. When one category does not cover 50% of the total area various decisions rules can apply. Determination of these rules, or other means of classifying a cell (percent types, weighted heirarchy, etc.) will be project specific. The decision rules should, however, try to retain the emphasis on speed of interpretation.

If a point system is also used, points will be classified according to the land category directly beneath them. Very small areas may be excluded, however. Again, these decision rules will be dependent on project requirements.

3. APPLICABILITY AND CONSTRAINTS

The technique described above is the way of extracting useful information from aerial photography. It is designed to be simple, inexpensive, and quick, and without the use of sophisticated equipment, highly skilled operators, or computer programs, it allows for extraction of geographically precise, accurate information. In addition, almost any type of aerial photography can be used. These attributes make it especially applicable for local and regional planning bodies with low budgets and large data needs, as well as for statewide or larger geographic areas where statistical information provided by point sampling can be very useful.

The method is dependent upon the availability of a base map series. The accuracy of the geographic alignment procedure is only as good as this map base. In order to maximize the efficient and speed of the operation, it is also necessary to maintain first order interpretation. first order interpretation requires that the classification of each feature on the imagery be immediately obvious to the interpreter, without recourse to measurements, keys or detailed examination of surrounding features. The level of detail obtainable from any given set of imagery is dependent upon the type and scale of photography and level of experience of the interpreters. However, the speed of the technique itself is basically independent of the number of categories to be identified so that, unlike most other data extraction methods, it costs little or no more to obtain information on 40 categories than it does on 10.

Finally, it should be noted that a general data extraction process has been described. It provides a technique which has been proven effective. Any user of the technique, however, can and should change it to meet his specific needs and resources.

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Figure 1 Paper Retrieval Sheet

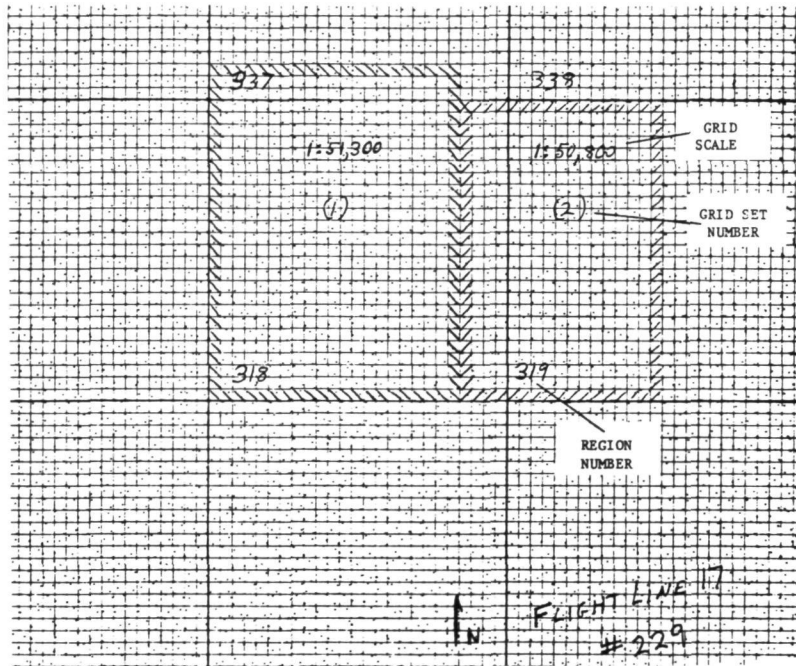
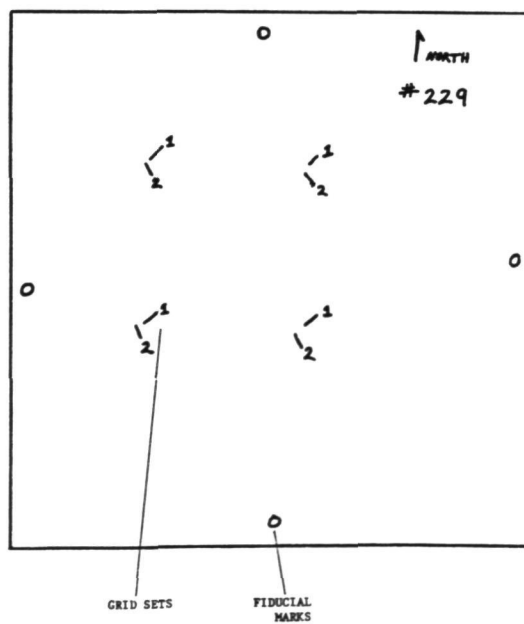


Figure 2 Mylar Retrieval Sheet



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APPLICATION OF CONVENTIONAL AND ADVANCED TECHNIQUES FOR
THE INTERPRETATION OF LANDSAT 2 IMAGES FOR THE STUDY OF
LINEARS IN THE FRIULI EARTHQUAKE AREA

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ABSTRACT

This work describes the results obtained in the study of linears derived from the analysis of Landsat 2 images recorded over Friuli during 1975. A particular attention is devoted to the comparison of several passes in different bands, scales and photographic supports. Moreover reference is made to aerial photographic interpretation in selected sites and to the information obtained by laser techniques.

I. FOREWORD AND AIM OF THE WORK

After the dangerous May 1976 earthquake (about 1000 people killed) a large research effort was focused in the Friuli area in order to reach a better geological and geophysical knowledge of the whole territory.

In this framework and interdisciplinary research was enterprised in order to evaluate the range of the contribution that the space coming data (Fig. I) could bring to geotectonic studies in these specific zones.

We analyzed the Landsat 2 images in a very detailed way in order to define:

- a) the best image properties, from bands and scales point of view, for the analysis of linear phenomena;
- b) a quantitative comparison of the Landsat images with aerial photographic interpretation over a selected site;
- c) the evaluation of the contribute of Fourier spectra laser techniques to the "objective" tracing of linear trends;
- d) a standard method to recognize and classify linears.^{oo}

2. GENERAL GEOLOGIC SETTING

Friuli region is located in the eastern part of Southern Calcareous Alps. The boundary with the Austrides coincides with the Gailtal line towards the North, whereas a transitional zone characterizes the boundary with the Dinarides s.s. towards the East.

^{oo} As linears we intend those phenomena which in satellite images exhibit a continuous "about linear" trend.

The following structural units can be distinguished from the North to the South (Fig.2): Carnic Range, Tolmezzo and Julian Alps, Carnic and Julian Prealps, Gorizia-Trieste Karst. The outcropping formation, 15.000 meters thick, range in age from the Ordovician to the Miocene. Most of them indicate marine and/or transitional environment. The youngest units are continental such as Clesian conglomerates of uncertain (Plio-Pleistocene) age, Würm moraines outcropping mainly in the Tagliamento morainic amphitheatre and the Holocene alluvial deposits of the plain. Ercinic orogeny involved paleozoic units with overthrusts and folds East-West directed and with South vergence (Fig.3). The main structural elements, connected with the alpidic orogeny, are overthrusts East-West directed and with South vergence in the southern area and North vergence in the northern one where there is a superposition with the ercinic structures. Units, outcropping and buried in the South East of the region, display overthrusts NW-SE directed (Dinaric system). All these structures, connected with alpidic compressive and distensive phases, are accompanied by a number of faults with N-S, NW-SE and NE-SW direction. Regional structures, created during alpidic orogeny (Lamaric phases and following ones), are presently accounted either to gravity flow, due to the uplift of the Alps, or collision between "adriatic plate" and the European continent.

3. IMAGE ANALYSIS

- Photointerpretation

The study of our images was done following these steps:

- a) analysis and drawing of linears (from Landsat 2 frames)
 - 1 - from I:1.000.000 positive film of band 7 (Fig.4)
 - 2 - from I:500.000 print of band 7
 - 3 - from I:250.000 prints (B&W) band 7 (Fig.5a) and 5 (Fig.5b)
- b) rose diagrams (Fig.6) compilation for length distribution of linears referred to the area of the image in different scales and bands
 - 1 - for angular grouping of 10° (Fig.6d)
 - 2 - for angular grouping of $22,5^{\circ}$ (Fig.6a,b,c)
- c) rose diagrams compilation for length distribution of linears (angular grouping : 10°) referred to structurally homogeneous blocks
 - 1 - from I:1.000.000 positive film (Fig.7)
 - 2 - from I:500.000 print (Fig.8)
- d) lineaments drawing in the area controlled by geologic map resources
 - 1 - from I:1.000.000 band 7 positive film of 9/10/75
- e) rose diagrams compilation (angular grouping : 10°) referred to the length of lineaments^{oo} of inferred tectonic source
 - 1 - from I:1.000.000 positive film in the whole geologically controlled area (Fig.9)
 - 2 - idem for each single block (Fig.10)

- Considerations

From the analysis of these Landsat 2 images of 1975(3 passes), the following considerations arise in the field of:

- a) interpretation

Band 7 exhibits a structural information content higher qualitatively than band 5; example:

b7 Dec 75 linears n.262 total length km 2989

b5 Dec 75 linears n.234 total length km 2119

(from I:250.000 print)

The b7 image recorded on 10th Sept (AZ I41^o, EL 42^o) shows a total number of linears higher

^{oo} As lineaments we intend those linears which upon an appropriate control show a clear geologic source of the phenomenon

than the 27th 75 one (AZ 152°, EL 15°) partly due to change in snow cover; example:
b7 Sept 75 linears n.470, total lenght km 4381
b7 Dec 75 linears n.218, total lenght km 2149
(from I:1.000.000 positive film)

The information derived from positive film (scale I:1.000.000) seems to be better detectable especially from a regional point of view in comparison with the corresponding prints also in more detailed scale.

In fact it was noted that the "long linear phenomena" have in general a lower level of comprehensive detectability in larger scales.

This is also partly due to the fact that the images recorded on positive films have more detailed countours and more accuracy in gray levels scale than the corresponding prints.

The rose diagrams of density and lenght of linears of two different periods (September and December '75) enhance in September the trends connected with NW-SE components (Dinaric system) while in December have no particular prevailing direction.

b) geology

Total field linears, which are the results of the analysis of Sept 75 I:1.000.000 positive film, were "filtered" in order to draw the lineaments of the area. It was not possible to classify the whole image, in fact the eastern portion (Jugoslavia) was lacking from the point of view of geological map resources.

Moreover due to the geologic complexity of the territory, the area interested at the highest level by May 6th 76 earthquake was divided into 4 blocks having homogeneous structural characteristics (Fig.4). The four blocks correspond to: A block-Tolmezzo Alps p.p.; B block-Julian Alps p.p.; C block-Julian Prealps; D block-Carnic Prealps p.p.

Density and lenght of linears and lineaments are computed and drawn by means of rose diagrams which gave rise to the following comparison:

1 - total field of lineaments (Fig.9) towards total field of linears (band 7 of Sept 10th and Dec 27th passes-Fig.6)

This fact may be due to the E-W component of the geologic structures in the area that could be enhanced by sun azimuth and elevation during the month of December

2 - Total field linears towards total field of lineaments in the four blocks: in these blocks the comparison linears-lineaments shows about equal values in C, a lower agreement in A and B, and a very different behaviour in D (Figg.7,8,10)

4. AERIAL PHOTOGRAPHIC INTERPRETATION

Just where the different behaviour was observed (D block p.p., Fig.4) a detailed photogeologic study with special reference to structural analysis was enterprised.

This area, with cover about 210 sq.km is part of Eastern Carnic Prealps, it is largely covered by mountains with sharp relieves raising from 200-400 meters a.s.l. of the bottom of the valleys up to 1700-1800 meters a.s.l.

A narrow belt of hills is present (300-400 meters a.s.l.) in the southern portion of the area. Detailed geologic surveys has been performed before the earthquake over the 2/3 of this territory by one of the authors.

They were brought to end subsequently, together with photogeologic analysis.

- Geologic setting

Most of the territory is formed, at the outcrop, by Mesozoic marine carbonatic rocks (U. Trias.U.Cretaceous).

Only in the southern portion Tertiary formations outcrop: they are represented by flysch facies (Maestrichtian p.p.-M.Eocene) and molasse (L.Oligocene-Pontian) deposits.

Quaternary continental deposits are of importance only locally.

Four overthrusts having South vergence are the largest outcropping geotectonics.

They are (moving from South to North): Arzino, Periadriatic, Tramonti and High Tagliamento overthrusts.

Moreover several faults systems are in this area; prevalently these faults have deep slopes

and the about NE-SW ones.

During the field surveys it was observed that:

- a) the faults having their directions between WNW-ESE and N-S displace systematically all the other structures, enclosed there in the overthrusts.
These faults can therefore considered as the most recent.
- b) The movements along these faults are, in the most of cases, of transcurrent type: there is a certain dextral shear tendency.
- c) Mesoscopic features show that also the overthrusts surface give rise to strike-slip movements if they have an about WNW-ENE trend.

- Photogeology

The photogeologic study having a structural purpose was performed utilizing B&W aerial photos (1:25.000 scale) taken in September 1969.

The linear features detected on the photos were drawn on topographic maps at the same scale.

Subsequently these elements were controlled by means of detailed geologic field surveys.

Therefore the lineaments reported and measured on the maps correspond in any case to movement planes, i.e., generally, to faults having different type and meaning.

On the whole 1418 lineaments were detected, amounting to a lenght of about 1369 km.

They are distributed in the following classes (Fig.II).

C1. 1^	(270°-280°)	km	39.363	%	2.9	n	64
2^	(280°-290°)		25.756		1.9		39
3^	(290°-300°)		62.935		4.6		47
4^	(300°-310°)		115.075		8.4		63
5^	(310°-320°)		76.237		5.6		52
6^	(320°-330°)		184.938		13.5		95
7^	(330°-340°)		204.570		14.9		114
8^	(340°-350°)		233.328		17.0		135
9^	(350°-360°)		163.589		11.9		117
10^	(0°-10°)		72.240		5.3		96
11^	(10°-20°)		33.475		2.4		86
12^	(20°-30°)		34.800		2.5		93
13^	(30°-40°)		21.825		1.6		84
14^	(40°-50°)		27.225		2.0		98
15^	(50°-60°)		23.700		1.7		80
16^	(60°-70°)		16.300		1.2		57
17^	(70°-80°)		12.525		1.0		42
18^	(80°-90°)		21.325		1.6		56

- Considerations

The results of this aerial photogeologic analysis agree perfectly with field collected data but exhibit overall difference when compared with Landsat 2 image interpretations. This event appears very clearly if it is considered not only the rose diagrams of the linears and lineaments of the whole area of the image (Fig.6-7) but expecially the ones referred to the single D block (Figg.7,8,10).

Many factors contribute to this discrepancy; among the most relevant ones we include:

- a) Landsat images sun azimuth and inclination.

This factor is of great influence in satellite images where lineaments corresponding in aerial photointerpretation to classes 5,6 and 7 appear very difficult or impossible to be detected

- b) Difference in scales, wavelenght and bandwidth between the two types of information .

Only the scale influence reduces passing from 1:1.000.000 positive film to 1:500.000 and to 1:250.000 prints. In this framework the comparison between Figg.6a-8d and between all these and Figg.6b,c is quite significant.(see also Fig.II)

- e) The "weight" of the new detected lineaments (air photos)

In the study of airphotos a lot of very narrow but continuous lineaments were detected (these lineaments correspond on field mainly to 4 + 10 classes).

These elements were partly unknown before this detailed analysis and for this reason they were not included in the geologic map resources utilized for linears-lineaments filtering.

5. OPTICAL FOURIER TRANSFORM ANALYSIS

The two-dimensional Fourier transform is well known. It starts from a coherent laser, in order to analyze the spatial distribution of the "frequencies" contained in a photographic image. A particular care in this work has been devoted to the preparation of the image which had to be examined and in the handling of the resulting optical Fourier spectra.

The investigated area was subdivided in squares 10x10 km sized: a network was laid on to the photographic derivative function image of band 7 (Dic 75).

The derivative function was obtained by superimposing a negative to the positive transparency and relatively shifting of about one scan-line in the sun azimuth direction the two slides.

In this way only the significant contrasts were emphasized, while the slowly changing phenomena disappeared completely.

Each square of the network was analyzed at laser light.

The corresponding Fourier transform spectra were recorded on photographic plate, and, at the same time, examined over 360° with a photomultiplier employing a 10° butterfly filter.

In that way, for each square, 36 measurements were obtained showing the $\pi/2$ rotated spatial distribution of the frequencies contained in the original information.

These series of data were filtered in order to avoid both the systematic and the random errors. A completely different approach was employed for the spectral analysis: a signal coming from a non-focused TV camera looking at the spectrum was treated with an analog slicer and displayed on a colour TV monitor.

The result of the non focusing process is that a point on the image becomes a small area, so that the distribution of points can be considered as a distribution of a photographic density that can be easily sliced.

In Fig. I2 the mosaic of the contours of an intermediate slicing level (the same for each square) is shown.

- Considerations

As it is easy to understand these two non conventional analysis have to be utilized with care in the interpretation step, because the geometrical distribution is an average of information about objects having the same direction, but is not possible to say anything about the meaning of such a distribution from a geological point of view.

When in a certain area, as the one of this study, a deep relationship exists between linears and lineaments, in this case the utilization of this methodology is useful.

In fact in this case the Fourier analysis can contribute to the definitions of "objective" regional geotectonic trends which are related to the geodynamic history of the territory.

From the comparison of the Fourier spectra and the rose diagrams of linears referred to structurally homogeneous blocks it was noted that a good agreement exists considering the A block trends; in the other ones this is also true except for the 20°-50° W sector.

Another comparison was done between the Fourier spectra and the rose diagrams of lineaments for the same blocks, taking into account that a quite good correspondence appears (except for D block) in the studied areas between linears and lineaments.

In this case a good agreement was found for C block, a fair one in A and B (obviously except for the 20°-50° W sector) and a marked difference in D in its Western side.

In this last block if the aerial photos are considered it is possible to observe a noticeable agreement just in Western sector between their rose diagram and the Fourier spectra (mosaic of the corresponding squares, Fig. I2).

The explanation of these data, basing on the type of analysis that was adopted, may be due to the presence of frequent, relatively short and discontinuous linears.

In fact they are not photointerpretatively emphasized in satellite images, but they appear very well detectable by Fourier spectra analysis of the same areas and clearly by aerial photogeology.

6. CONCLUSIONS

The research performed utilizing satellite images, aerial photography and field surveys in a combined approach for the study of linears in Friuli earthquake area, suggests, at this step, the following considerations:

- a) For the identification and classification of linear phenomena revealed by Landsat images it is mandatory at the beginning to compare for the same territory different passes, bands and scales.
In the images of Friuli it was ascertained that the most information was recorded in b7 positive film, 1:I.000.000 scale, 9.10.75 orbit.
- b) The differences verified in Landsat and aerial photographic information are mainly due to the different capability in perceiving the evidence of long and short linear phenomena at the surface.
In fact aerial photographic analysis revealed small and discontinuous elements which are very difficult to be discerned, identified, and "weighed" in the normal photointerpretative approach to Landsat images.
- c) Fourier spectra analysis applied to satellite data, besides confirming "normal" linear trends detected by the photointerpretation of selected frames, appears as a powerful method in evaluating exactly the small and detailed elements (at satellite observation scales). As a matter of fact Fourier spectra analysis revealed a trend (20°-30° W about) not evident in Landsat images photointerpretative stage and that, on the other side, was very clear in aerial photographic interpretation. This is possible obviously in zones where a quite close linear-lineament interdependence exists.
- d) As a standard methodology, for the analysis of space coming data in area exhibiting a similar behaviour from a geologic and climatic point of view, this research seems to suggest the following steps:
 - 1 - choice of a proper b7 image taken in late Summer or early Autumn
 - 2 - linears drawing from 1:I.000.000 positive transparency
 - 3 - linears-lineaments preliminary geologic filtering
 - 4 - Fourier spectra analysis, driven for the selection of the size of the square elements by the geologic evidence of the territory on study
 - 5 - comparison between the trends shown by Fourier spectra analysis and the ones obtained by satellite image photointerpretation
 - 6 - aerial photointerpretation in those areas where the most discrepancy appears (see point 5) and as a spot check-up in few sites (to be selected on the basis of the geologic complexity of the territory)

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FIGURES

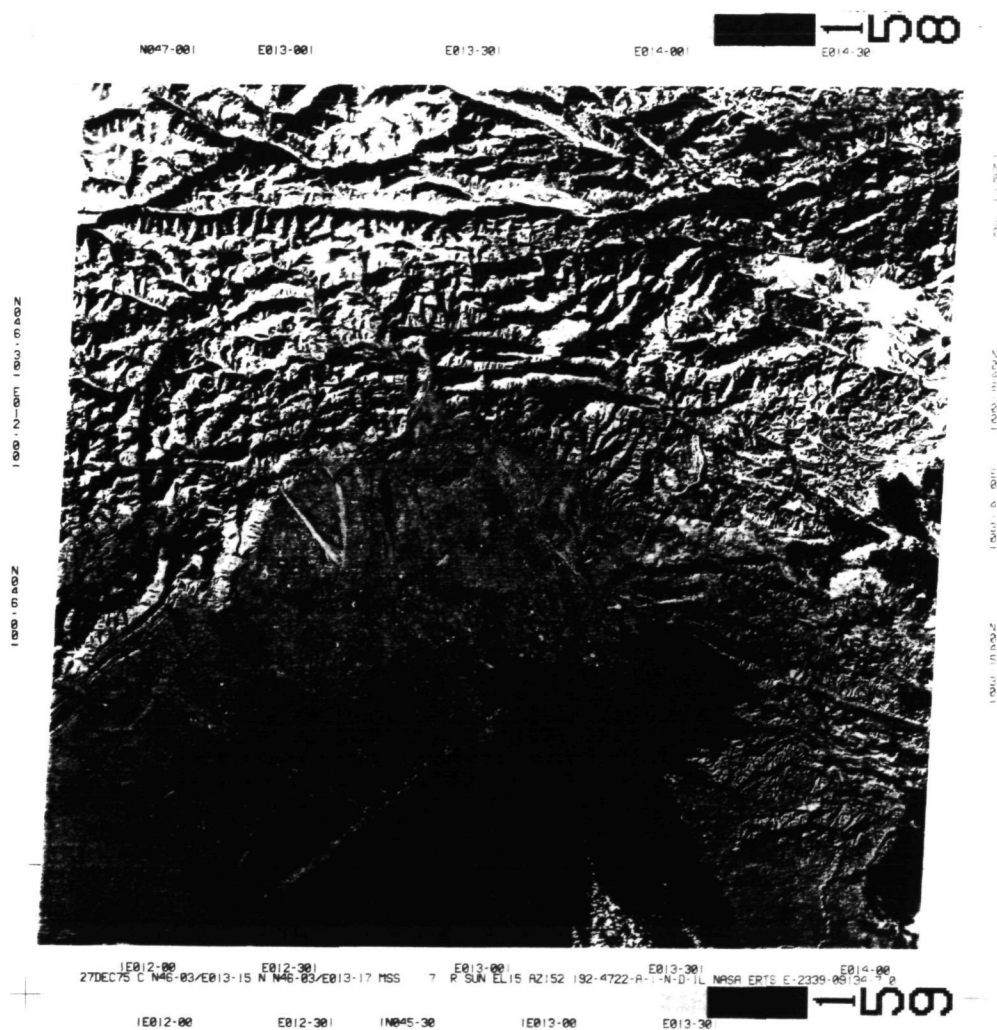


Fig. I - Friuli and surrounding areas. MSS band 7 Landsat 2 image (12.27.75 orbit) printed from 70mm negative film

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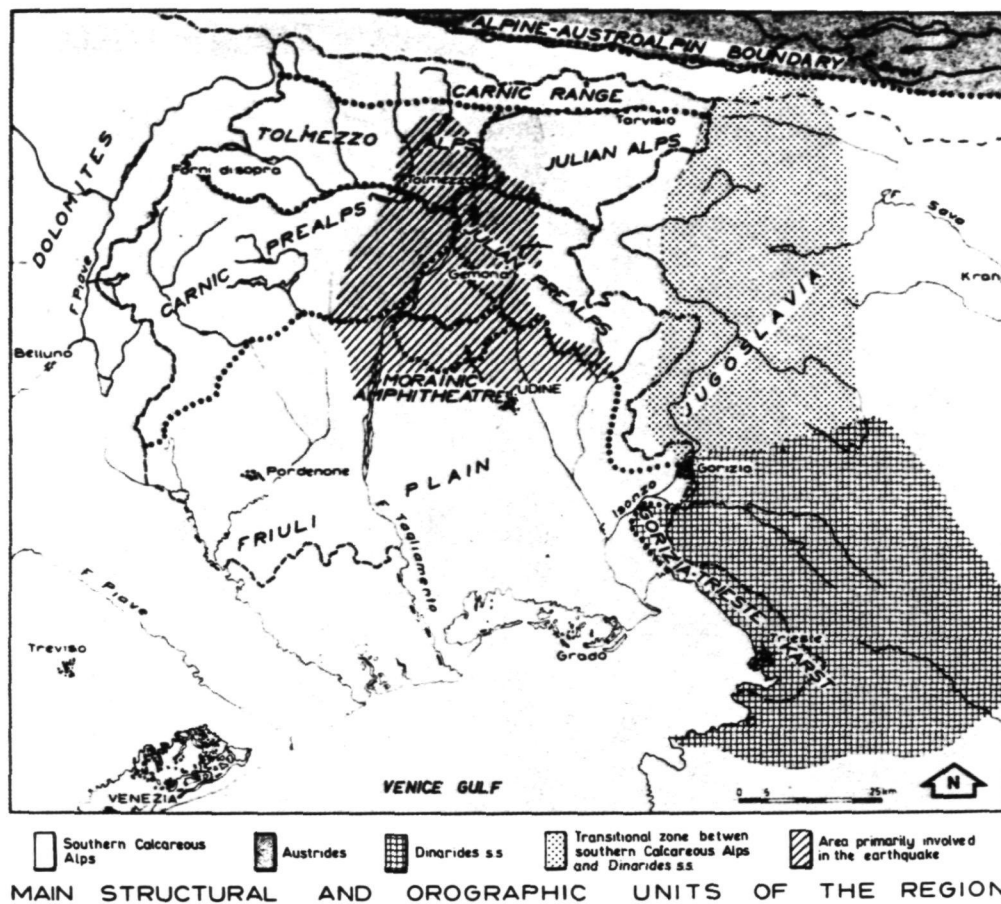


Fig. 2 - Main structural and orographic units of the region

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TECTONIC SKETCH-MAP OF FRIULI

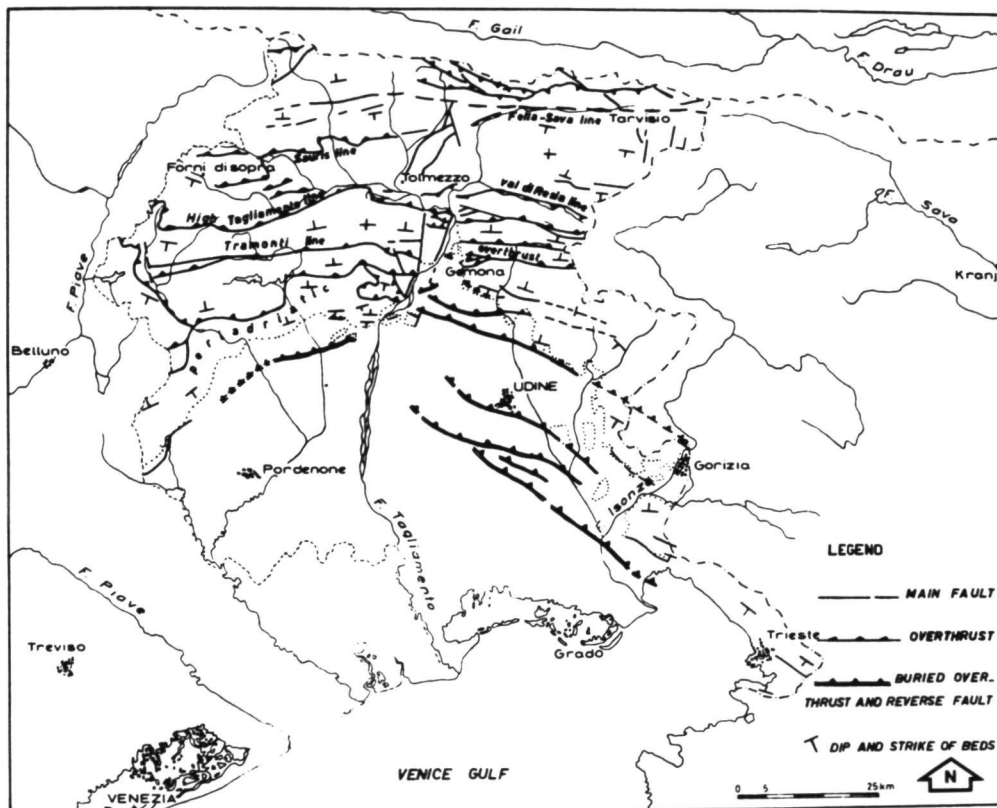


Fig. 3 - Tectonic sketch-map of Friuli

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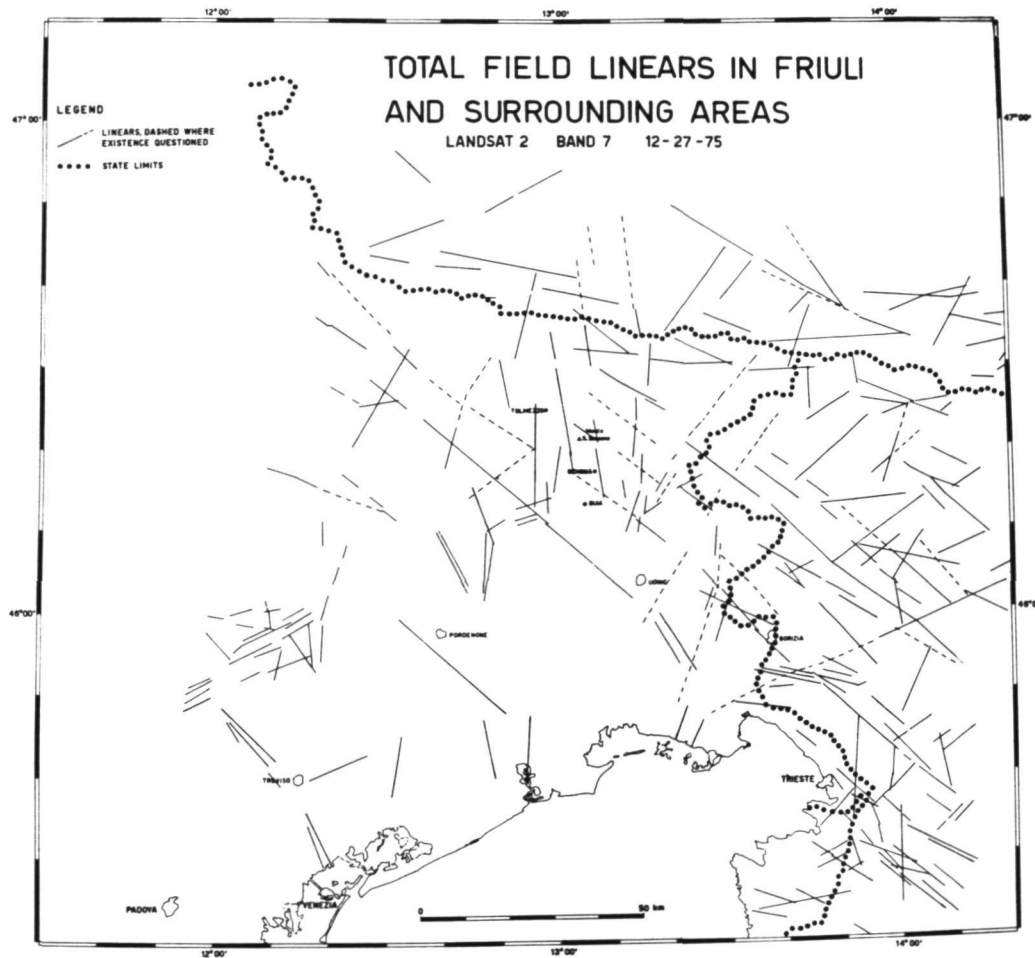


Fig. 5 a - Total field linears in Friuli and surrounding areas from
b7, I:250.000 print (I2.27.75 orbit)

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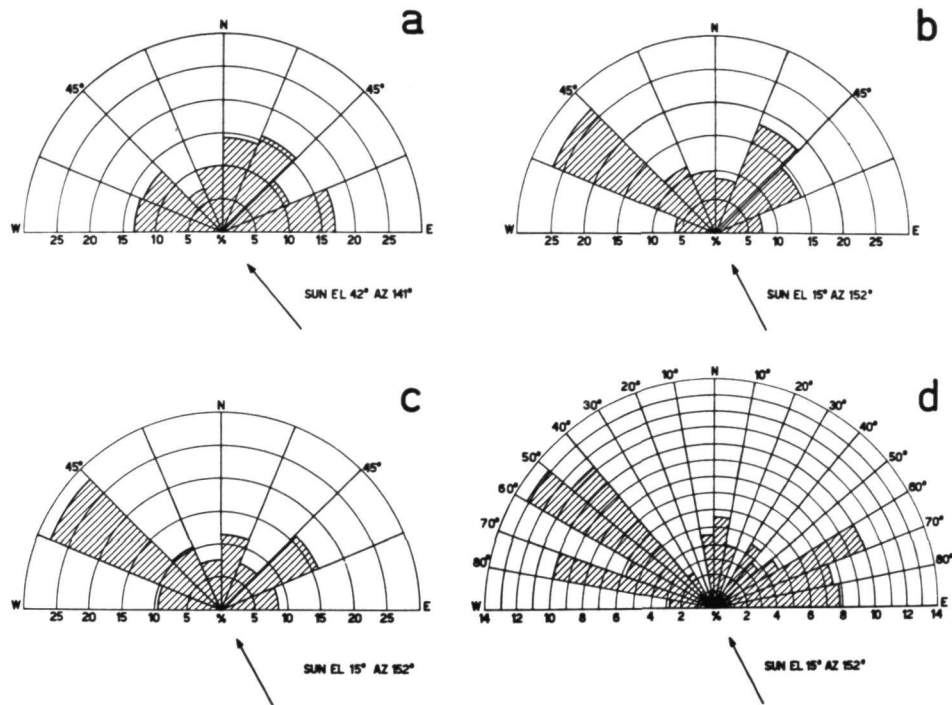


Fig. 6 - Rose diagrams (length distribution) of linears referred
to the whole area of the image
a) from b 7 I:1.000.000 positive film (9.10.75)
b) from b 7 I:250.000 print (12.27.75)
c) from b 5 I:250.000 print (12.27.75)
d) from b 7 I:500.000 print (12.27.75)

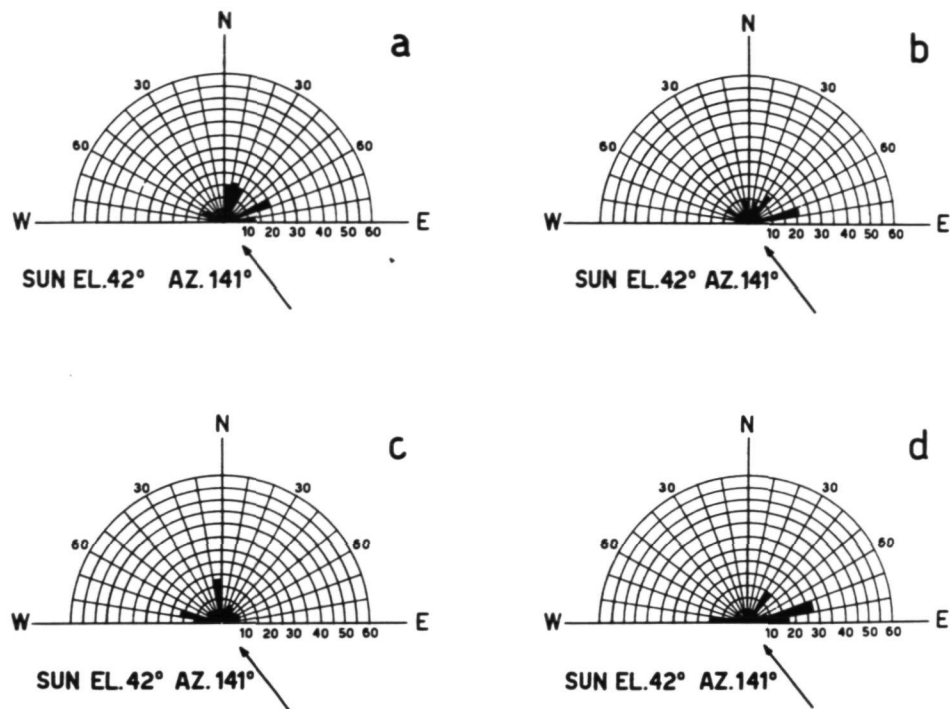


Fig. 7 - Rose diagrams of linears referred to structurally homogeneous blocks (a,b,c,d correspond to A;B,C,D blocks of 4). The diagrams are derived from b 7 I:1.000.000 positive film (9.10.75 orbit, Fig.1)

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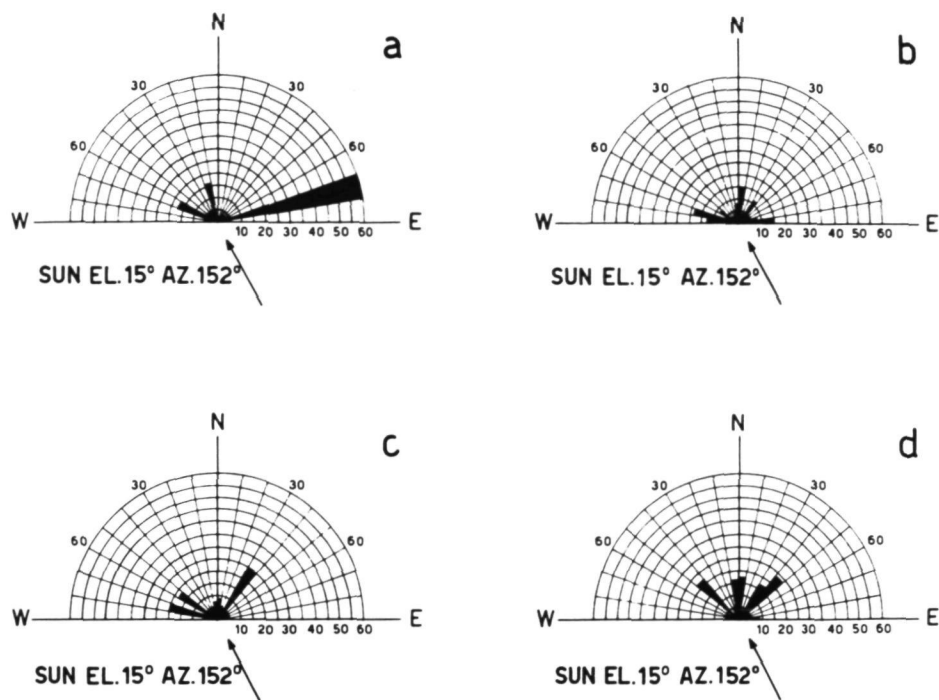


Fig.8-Rose diagrams of linears referred to structurally homogeneous blocks (a,b,c,d correspond to A,B,C,D blocks of Fig.4). The diagrams are derived from b7 I:500.000 prints (I2.27. 75 orbit)

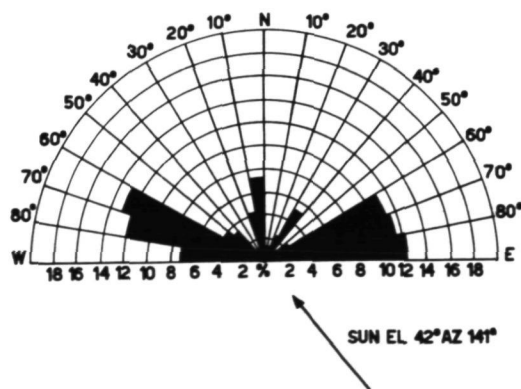


Fig.9-Rose diagrams from b7 positive film (9.10.75 orbit) drawn from the whole geologically controlled area

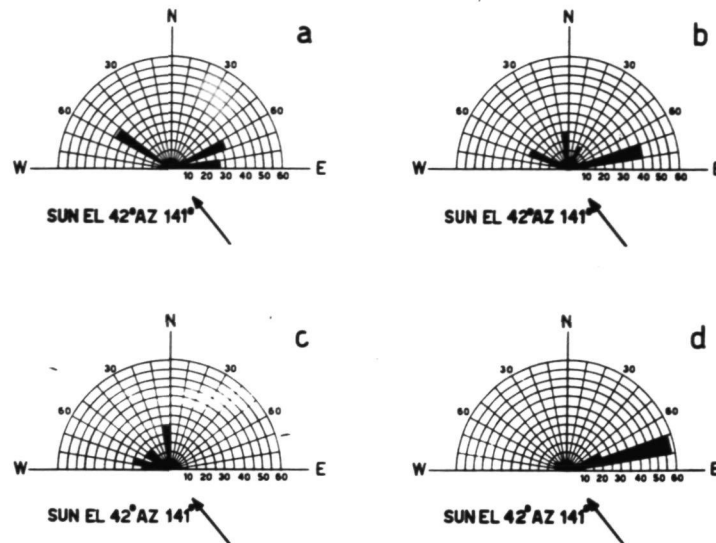


Fig. IO - Rose diagrams of lineaments from b7 positive film (9.I0.75 orbit) drawn for each single block

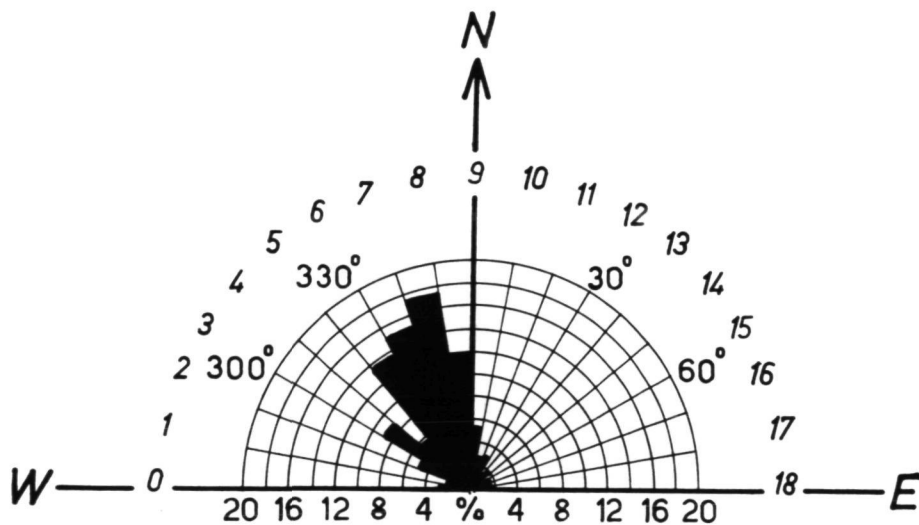


Fig. II - Rose diagrams (length distribution) of lineaments detected on B&W air photos of the Tolmezzo-Trasaghis-Forgaria area

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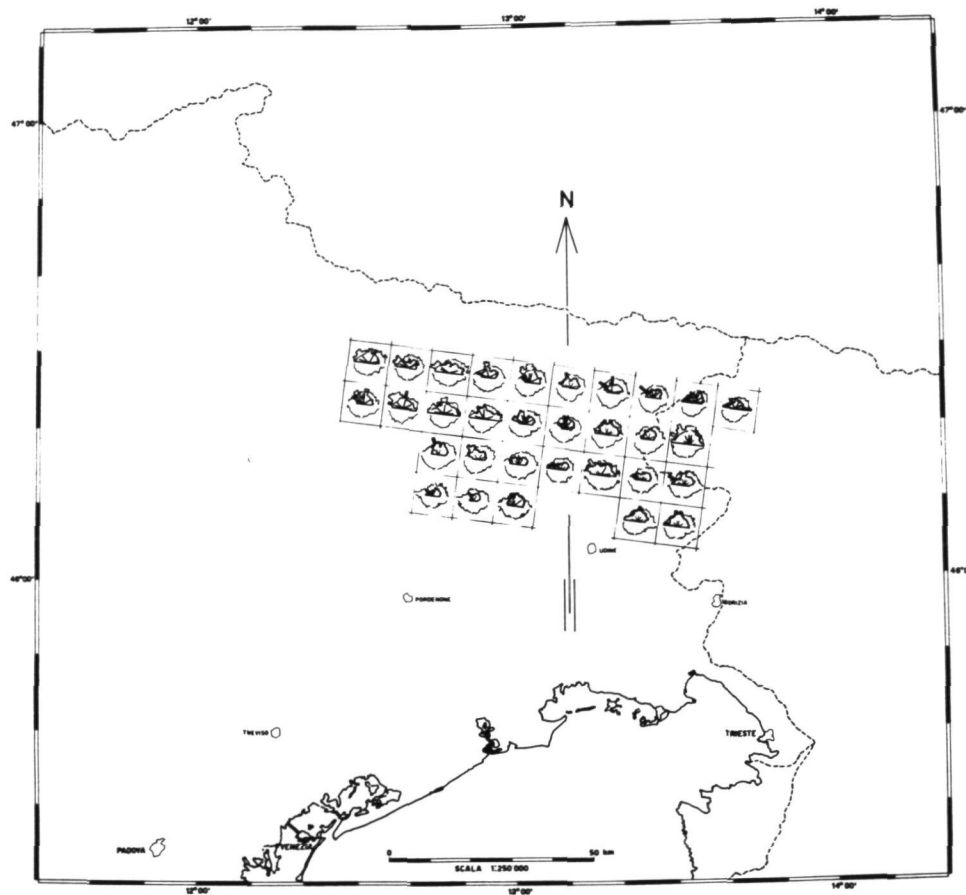


Fig. I2 - Mosaic of the results of Fourier analysis (assemblage of the whole cells):

- 1) the irregular contours correspond to analog representation of Fourier spectra.
- 2) The rose diagrams correspond to photomultiplier angular survey.
- 3) The arrows are, in a qualitative form, the interpreted trends.

APPLICATION OF LANDSAT SATELLITE IMAGERY

FOR IRON ORE

PROSPECTING IN THE WESTERN DESERT OF EGYPT

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SUMMARY

Prospecting for iron ore occurrences has been conducted by the Remote Sensing Center in Bahariya Oasis-El Faiyum area covering some 100,000 km² in the Western Desert of Egypt. Landsat-1 satellite images have been utilized as the main tool in the regional prospecting of the iron ores.

The delineation of the geological units and geological structures through the interpretation of the images corroborated by field observations and structural analysis led to the discovery of new iron ore occurrences in the area of investigation. A new locality for iron ore deposition namely that of Gebel Qalamun has been discovered accordingly, as well as new occurrences within the already known iron ore locality of Bahariya Oasis. The previously mentioned localities have been recommended for immediate detailed exploration using airborne and ground remote sensing techniques. Six other localities have been further recommended for long term exploration. The geological exploration criteria found out during the present investigation include the geological units ranging in age from Cretaceous to Eocene and the superimposed Laramide folding.

The structural features of the newly discovered Gebel Qalamun locality, as well as other new occurrences in the environs of Bahariya Oasis locality showing on Landsat satellite images are comparable to those of the already known iron ore deposits in the latter locality. The iron ore deposits of El Gedida, Gebel Ghorabi and El Harra are noted to be mostly located on crenulations representing hinge areas of meso or macro folds with axial traces attaining an approximately NE-SW direction. Moreover, the iron ore deposits at El Heiz are likewise located on crenulations representing hinge areas of meso or macro folds. However, at least two generations of folding have acted on the strata of Bahariya Oasis locality and its iron ore deposits, as the final folding traces acquire trends varying from NW-SE to NNW-SSE. The tectonic setting of the newly discovered iron ore occurrences and those of the already known iron ore deposits is controlled by the same forces which led to the deposition of iron ores in comparable localities regarding both time and space.

INTRODUCTION

A geologically favorable area for the deposition and accumulation of iron ores has been selected in the Western Desert of Egypt to conduct regional prospecting for these ores at the request of the Egyptian Iron and Steel Company. The area in question, termed Bahariya Oasis - El Faiyum area (El Shazly, Abdel Hady, El Ghawaby and Khawasik, 1976), covers 100,000 km² which represents 10% of the whole coverage of the Egyptian territories. Due to the great extension of the area of investigation and the limited time available to carry out the project, which is less than one year, LANDSAT-1 satellite images have been utilized as the main prospecting tool for iron ore occurrences.

As the regional prospecting for iron ores in Bahariya Oasis-El Faiyum area is essentially governed by the geological units which host the iron ores and the structures which control their deposition and accumulation, maps of geolo-

gical units, structural lineaments and drainage have been constructed for the area in question on scales of 1:500,000 to 1:250,000 based on LANDSAT imagery, intensive field measurements and structural analysis. The images used include black and white positive transparencies and prints in bands 4, 5, 6 and 7 of the multispectral scanner carried on LANDSAT-1, false color composite transparencies and prints produced from various combinations of three of the previously mentioned bands, as well as some images digitized from the computer compatible tapes.

All images have been subjected to detailed photo interpretation. It has been found out during this process and previous experience gained in the prevailing arid conditions of the Egyptian deserts that the transparencies are superior to the opaque prints, and that in addition to the false color composite transparencies images of bands 5 and 7 are most helpful in delineating the geological units, structural lineaments and drainage lines.

Due to the particular importance of structural elements in the localization of iron ore occurrences the numerous field structural measurements obtained have been treated by a structural analysis technique to determine the major structures in the area of investigation which could not be fully investigated in outcrops and their geometrical elements. The technique in question is based on viewing the linear structures and the normals of the planar structures as vectors of a unit magnitude each (Ramsay, 1967; Koch and Link, 1971).

LITHOLOGIC CRITERIA FOR IRON ORE PROSPECTING

Prospecting for iron ores in Bahariya Oasis - El Faiyum area is closely connected with the identification on LANDSAT-1 imagery of the lithologic units favorable for hosting these ores, and the delineation of such units on the interpreted geological maps (Figures 2 and 3). This method is of direct nature and has been previously applied by El Shazly, Abdel Hady, El Ghawaby and El Kassas (1974) for the recognition of iron ore deposits and phosphorite beds on LANDSAT-1 images in East Aswan area, Egypt. In the latter locality the iron ores are restricted to the medium textured iron ore member which has the darkest color among the various members of the Nubian Sandstone. On the other hand, the phosphorite beds represent an integral part of the phosphate-bearing formation which is characterized by its very coarse texture and medium grey tone.

Examination of the satellite images of the investigated Bahariya Oasis-El Faiyum area reveals striking similarities between Bahariya Oasis and Gebel Qalamun environs, located in the western and eastern parts respectively of the considered area at long distances from each other (Figure 1). Iron ore deposits have been previously known at El Gedida, Ghorabi and El Harra in the environs of Bahariya Oasis where they occur essentially in Middle Eocene sedimentary rocks (Ball and Beadnell, 1903; El Shazly 1962 a and b; El Akkad and Issawi, 1963; El Bassyouni, 1972; etc.). The latter are characterized, in the appropriate LANDSAT images, by the presence of white chalky horizons intercalated by dark grey beds of limestones and clays of ferruginous nature. Sediments with comparable characteristics and age have been identified on LANDSAT images in Gebel Qalamun environs. Field investigations which followed this identification and delineation proved the presence of iron occurrences at Gebel Qalamun locality outcropping along a curve attaining some 70 kilometers in length (Figure 7). The geological unit hosting the iron deposition has been found by lithostratigraphic measurements to be correlatable to the lower formation, named Gebel Qalamun Formation, of the Middle Eocene sediments where the known iron ore deposits in the environs of Bahariya Oasis are present. In Gebel Qalamun environs the shaly horizons of the formation in question are the ones incorporating the iron minerals.

STRUCTURAL CRITERIA FOR IRON ORE PROSPECTING

The structural lineaments interpreted from LANDSAT-1 imagery are discriminated as linear elements such as fractures and faults or as curved elements representing folds. One of the great advantages of using LANDSAT imagery is the elucidation of major regional lineaments, thus enabling the detection of their interconnections and their correlation over large areas.

The structural pattern of the investigated Bahariya Oasis-El Faiyum area has been formulated in three stages starting with the delineation of the structural lineaments on the most suitable LANDSAT images, followed by checking and measuring of the structures in the field, and finally by computer programmed analyses of the structural elements.

The similarity of the structural elements, notably folds, in the environs of Bahariya Oasis (Figure 4) and Gebel Qalamun (Figure 5) has been noted at an early stage of the work as has been the case with the lithologic units. This has led to the orientation of prospecting towards the discovery of iron occurrences in the environs of Gebel Qalamun. Furthermore, the structural investigations carried out in the environs of Bahariya Oasis proved that the already known iron ore deposits are related spatially to small hinge zones of plunging synclines and anticlines imposed on the host rocks. It may be added here that Bahariya Oasis main anticlinal structure has been built up by an older folding with an axial trace striking NNE-SSW which has been modified by a younger one to acquire an axial trace striking NNW-SSE.

The same structural features noted in the already known iron ore deposits have been also encountered in other localities in the environs of Bahariya Oasis, and accordingly the latter are recommended for further detailed prospecting in three successive time periods according to their priority. In the whole area of investigation priority No.1 has been given to Northern Bahariya Oasis locality 1 (Figure 6) and Gebel Qalamun locality 2 (Figure 7). The choice of localities belonging to priority No.1 is based on favorable geological and structural conditions, the presence of iron deposition in exposures or under shallow depths, and the relative cheapness of the infrastructure required to develop such localities. Priority No.2 is assigned to Qaret Had El Bahr locality 3 and Ghard Ghorabi locality 4 in the vicinity of Bahariya Oasis, and West El Faiyum locality 5 westwards of Gebel Qalamun. Localities selected under priority No.2 possess favorable structural conditions while their infrastructure may be connected with that of localities of priority No.1. Localities belonging to priority No.3 include those of Central Bahariya Oasis locality 6, Southern Bahariya Oasis locality 7 and West Giza locality 8. The localities in question require separate infrastructure and may exist in the subsurface at considerable depths.

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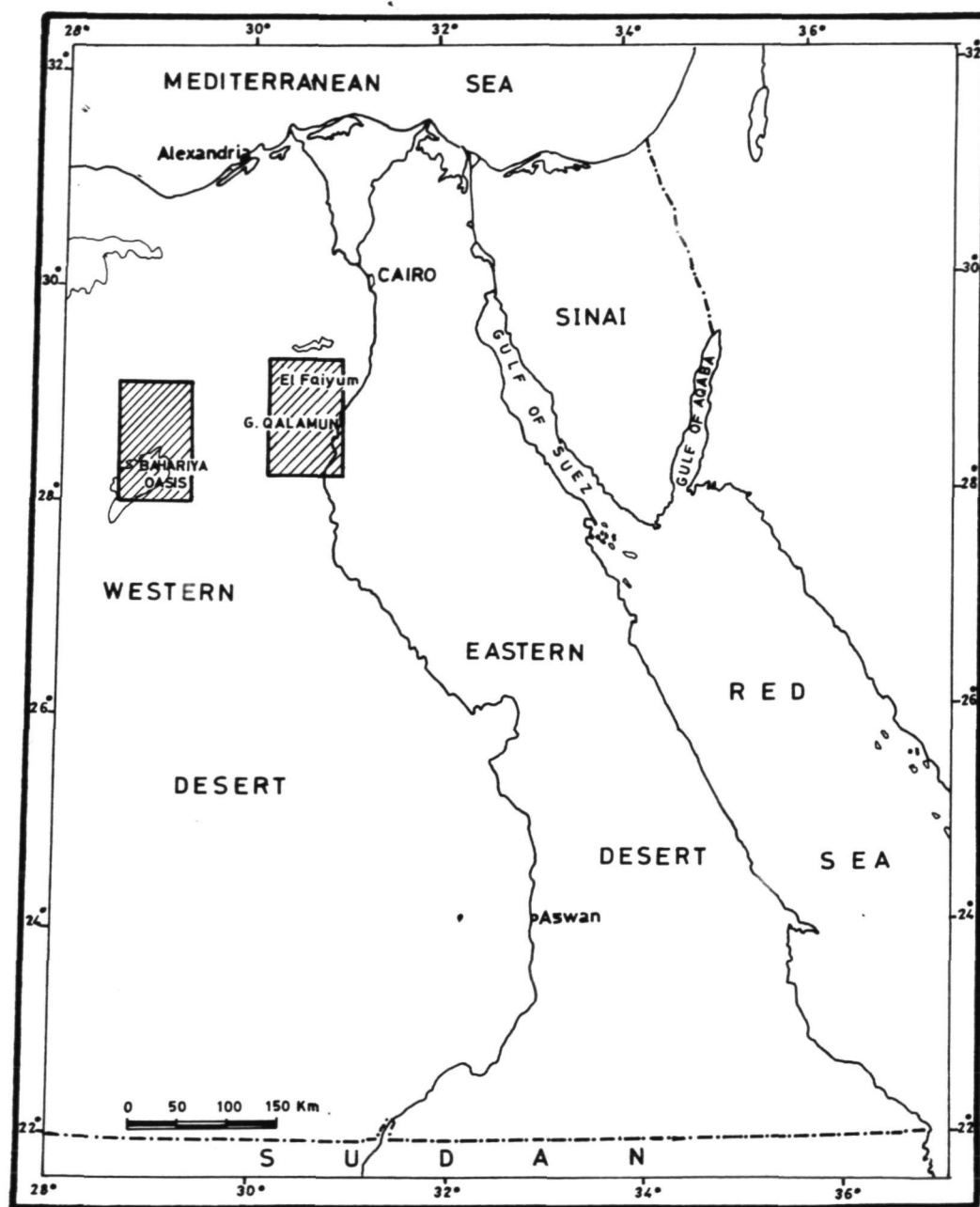


FIGURE 1. LOCATION MAP OF BAHARIYA OASIS AND GEBEL QALAMUN ENVIRONS, WESTERN DESERT, EGYPT.

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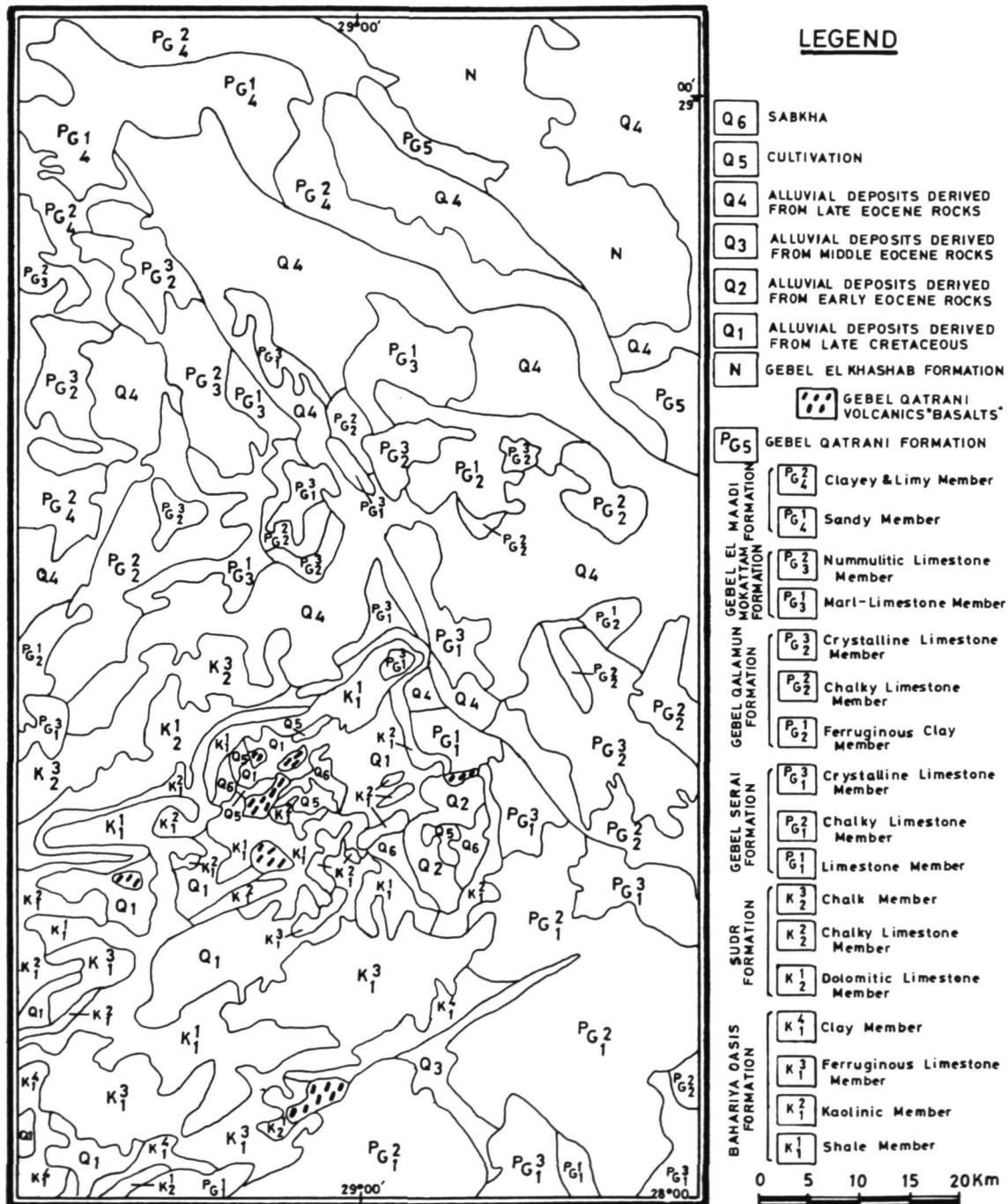


FIGURE 2. GEOLOGICAL MAP OF BAHARIYA OASIS ENVIRONS.

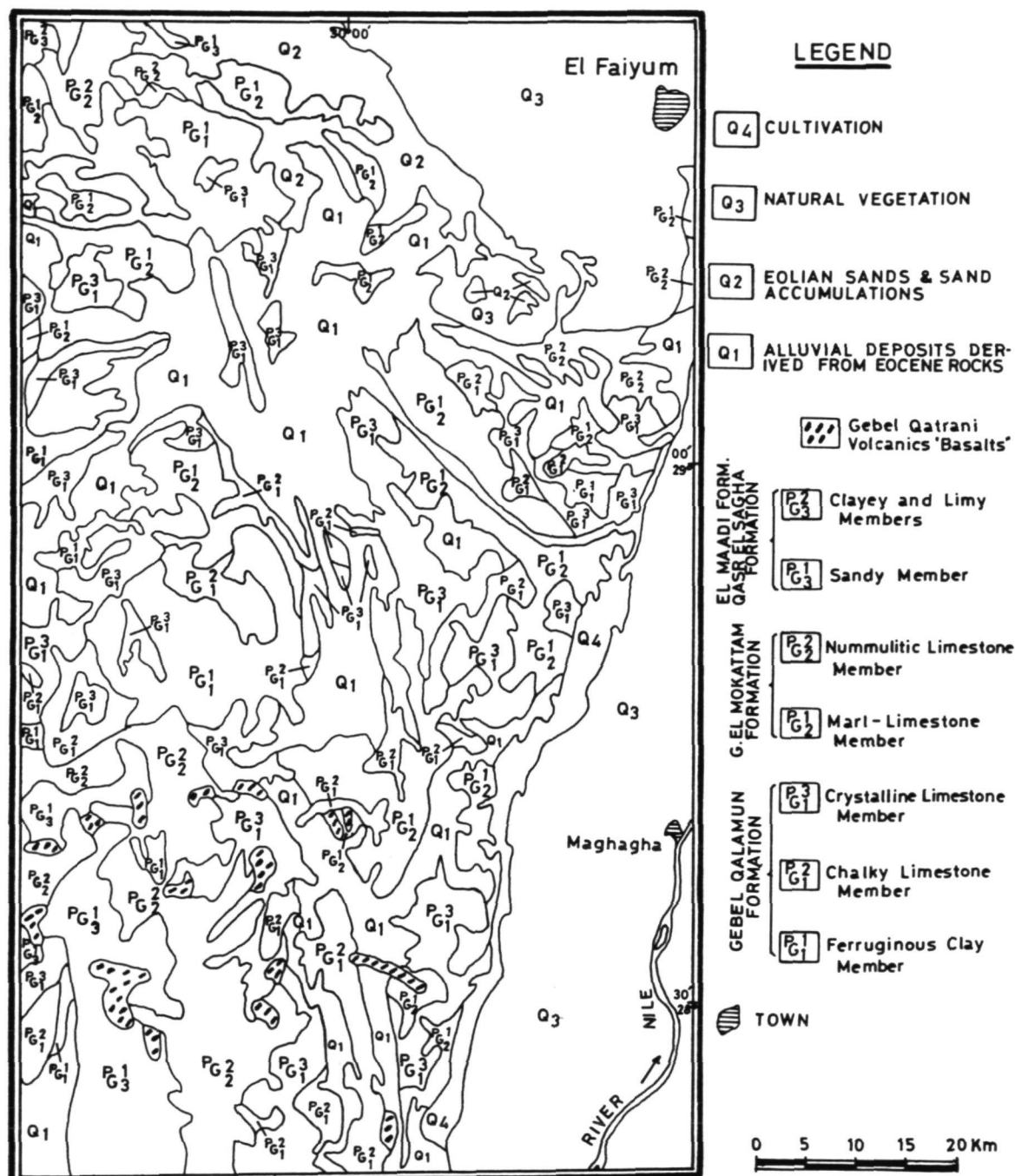


FIGURE 3. GEOLOGICAL MAP OF GEBEL QALAMUN ENVIRONS.

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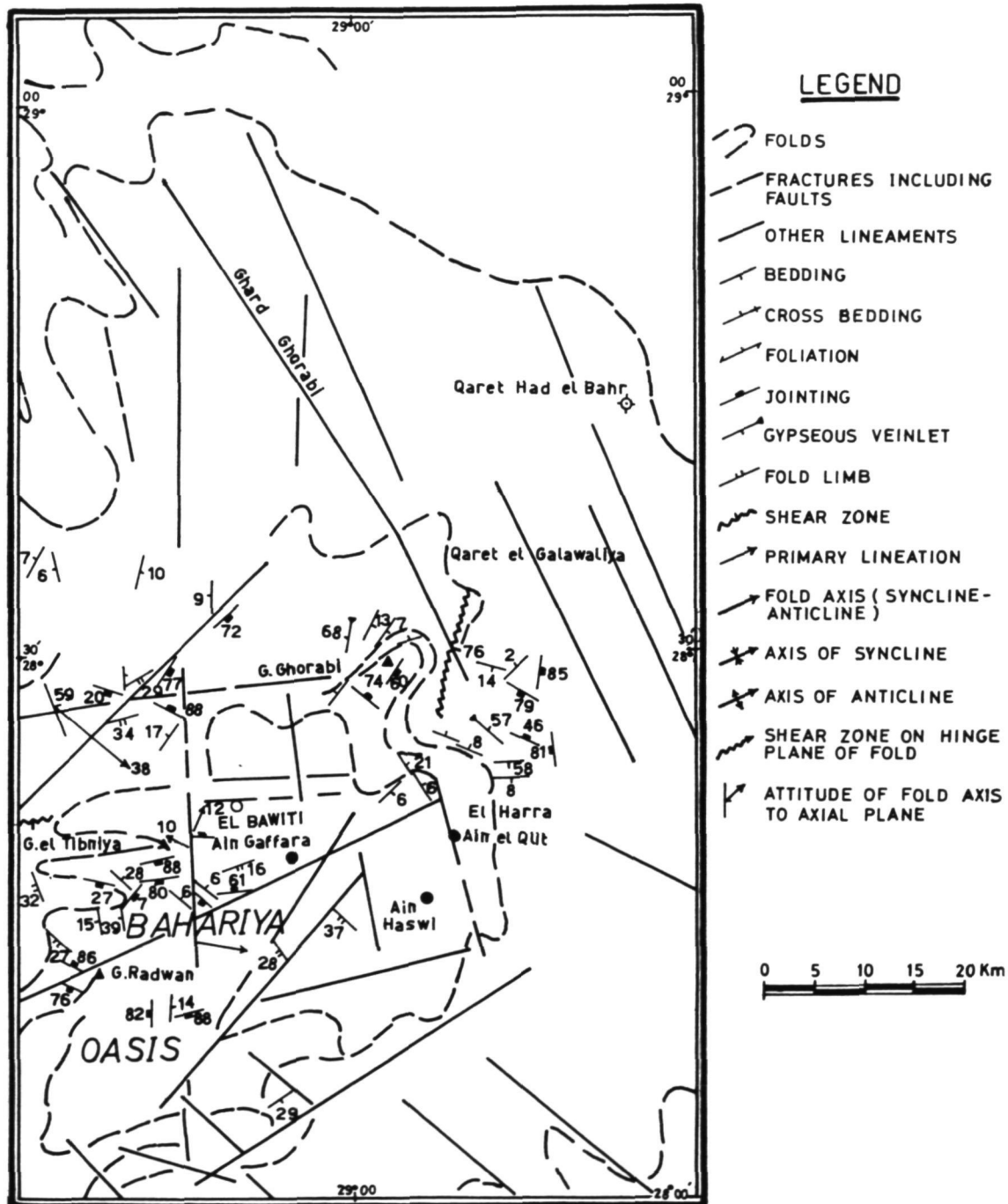


FIGURE 4. STRUCTURAL MAP OF BAHARIYA OASIS ENVIRONS.

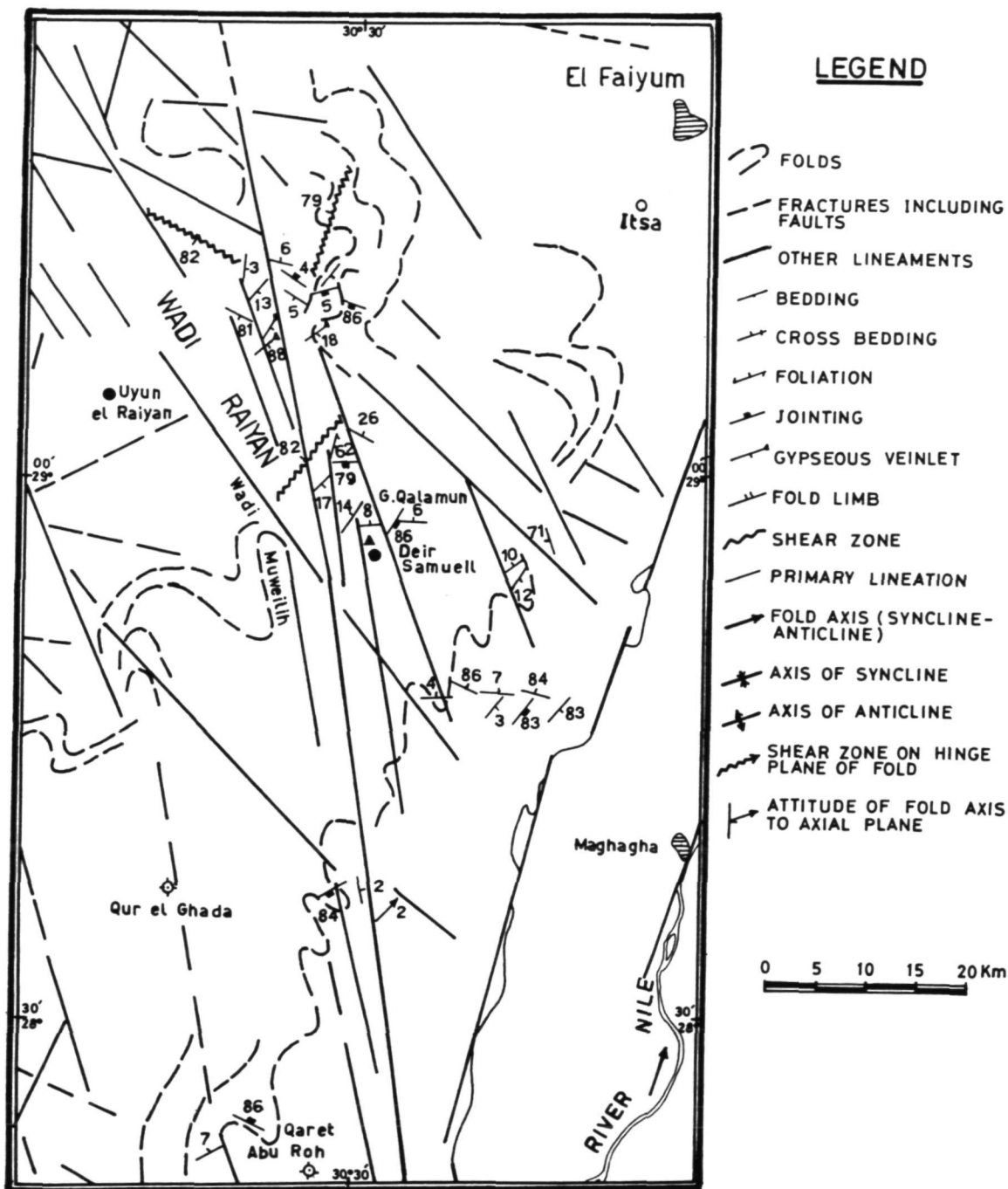


FIGURE 5. STRUCTURAL MAP OF GEBEL QALAMUN ENVIRONS.

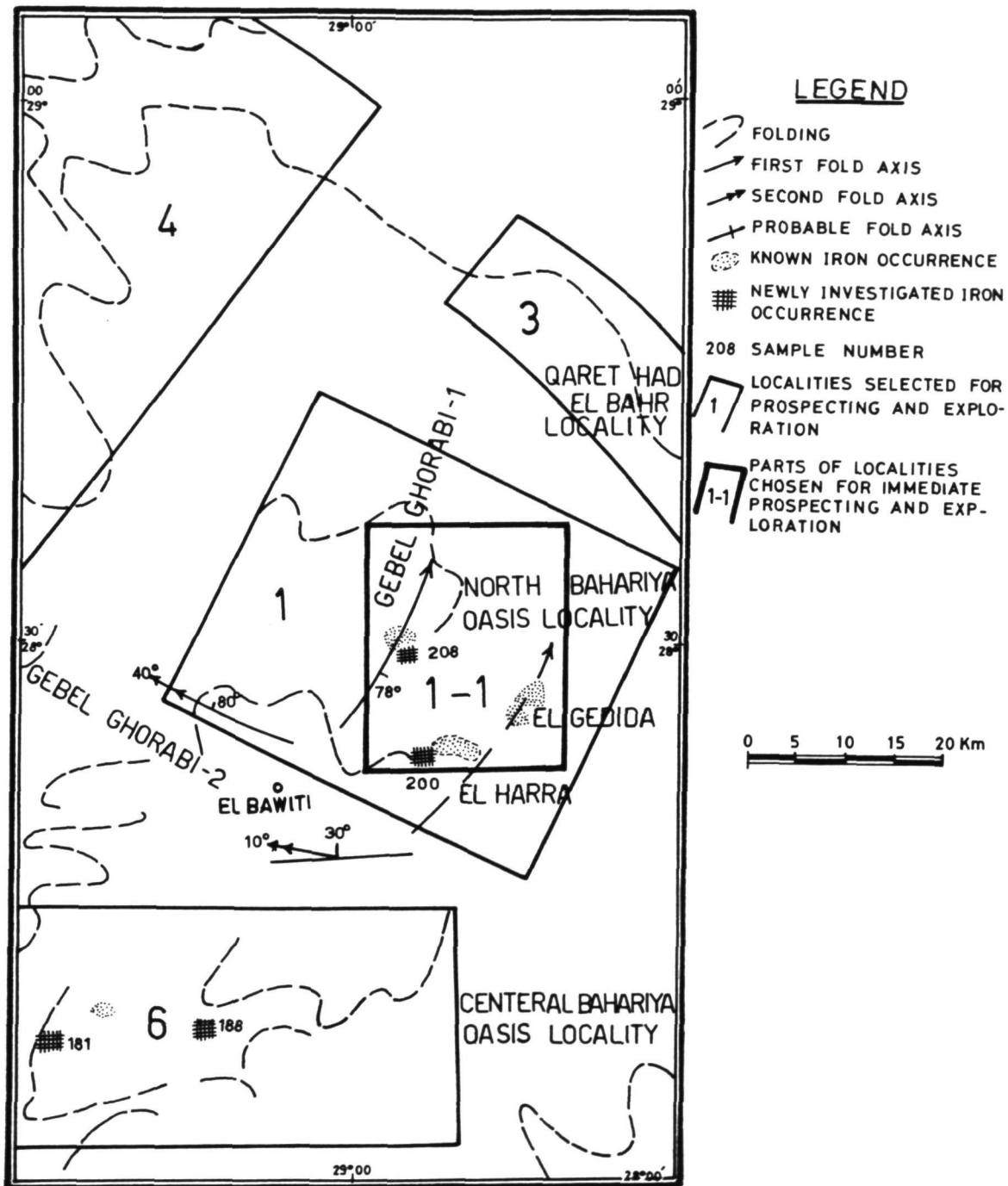


FIGURE 6. LOCALITIES SELECTED FOR IRON ORE PROSPECTING, BAHARIYA OASIS ENVIRONS.

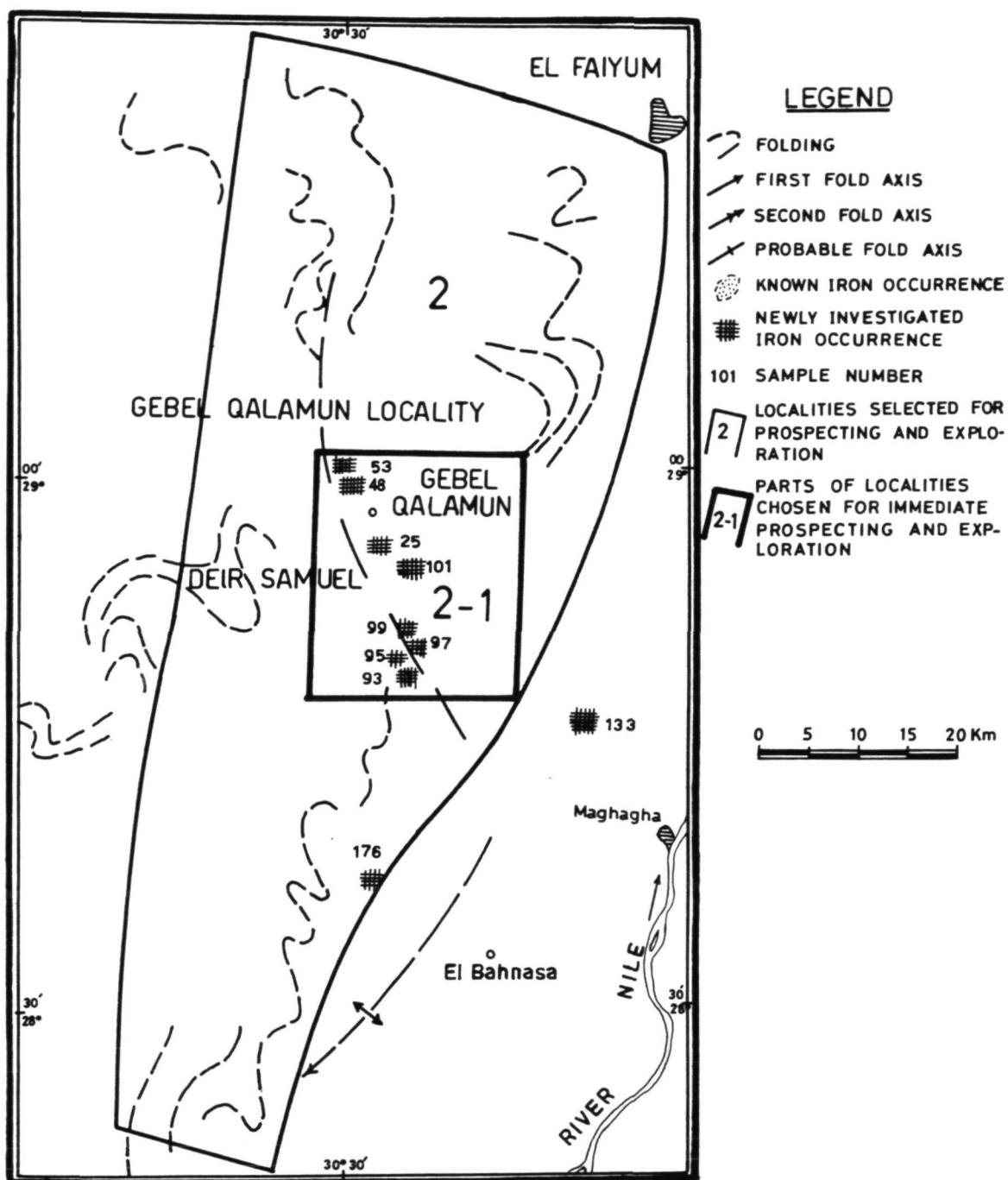


FIGURE 7. LOCALITIES SELECTED FOR IRON ORE PROSPECTING, GEBEL QALAMUN ENVIRONS.

N78-14582

GROUNDWATER STUDIES IN ARID
AREAS IN EGYPT
USING LANDSAT SATELLITE IMAGES

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SUMMARY

About ninety seven percent of the land of Egypt is covered by deserts lying in one of the major arid zones of the world. These deserts include the Western Desert, the Eastern Desert and the Peninsula of Sinai. Groundwater represents an important problem to be tackled for the development of these deserts and their utilization.

The interpretation of LANDSAT satellite images for large areas in the deserts of Egypt has been going on for more than four years, and its comparison with the pertinent information on groundwater aquifers in these areas deciphered a considerable number of questions regarding the conditions, source and potential of the groundwater.

Various features are interpreted which have strong bearing on groundwater in the arid environment. These include the nature of geological and lithologic units, structural lineaments, present and old drainage systems, distribution and form of water pools, geomorphologic units, weathering surfaces and other weathering phenomena, desert soils, sand dunes and dune sand accumulations, growths of natural vegetation and agriculture, and salt crusts and other expressions of salinization. The same features could be utilized in the regional exploration and management of groundwater aquifers in the arid zones.

There are many impressive examples which illustrate the significance of satellite image interpretation on the regional conditions of groundwater which could be traced and interconnected over several tens or even several hundreds of kilometers. This is especially true in the northern Western Desert of Egypt where groundwater issuing from deep strata comes to the surface along ENE-WSW and ESE-WNW fault lines and fracture systems. Fresh to brackish and saline springs, and water pools in the depressions of this part of the Western Desert owe their origin to this striking phenomenon. These include Siwa Oasis Depression, Qattara Depression and El Bahrein Depression. In fact, the livelihood of the population of Siwa Oasis depends on such springs and pools.

Another striking example is illustrated by the occurrence of fresh to brackish groundwater on the Mediterranean Sea Coastal Zone of the Western Desert where the groundwater is found in the form of lenses floating on the saline sea water. This phenomenon is caused by the presence of certain highly porous and permeable detrital limestones which belong to a geological unit, extending along the coast, called Alexandria Formation. This latter unit has been delineated along a distance on the coast of some five hundred kilometers, accurately and in a short time by the interpretation of LANDSAT satellite imagery.

INTRODUCTION

The territories of Egypt cover one million square kilometers (Figure 1), of which some 700,000 square kilometers have been mapped by the Remote Sensing Center in Cairo through the application of LANDSAT imagery. The maps are normally produced on a scale of 1:500,000 and they are usually reduced for the

sake of publication to the handy scale of 1:1,000,000.

The prevailing very arid to arid conditions over the country necessitate the dominance of desert conditions in general with the exception of the Nile Valley where the fertile lands are irrigated by the water of the River Nile. Dispersed cultivations are noted in the peripheries of the Nile Valley, in the Mediterranean Sea Coastal Zone where annual rainfall may range between 150 and 200 mm and the groundwater is accessible, and in some oases and valleys where groundwater is stored in aquifers under conditions favorable for exploitation. The cultivated lands of the Nile Valley represent 3% of the coverage of Egypt, while the remaining 97% of the lands are deserts where dispersed cultivations may be present under special conditions.

LANDSAT imagery are available as computer compatible magnetic tapes and as printed images which are made on positive transparencies or opaque prints for each of the four bands of the multispectral scanner mounted on LANDSAT satellites. These are bands 4, 5, 6, and 7 corresponding to the green, red and two near infrared spectral ranges respectively, of which bands 5 and 7 have been found most suitable for mapping in the prevailing natural conditions of Egypt especially in positive transparencies. Mixing and ratioing of combinations of three of the four bands produce false color composite images, which are utilized for mapping especially, in their positive transparencies, in addition to the previously mentioned images of bands 5 and 7. The computer compatible tapes mounted on Bendix M-DAS system provide enlarged and digitized LANDSAT imagery and facilitate mapping of the natural units and phenomena in great diversification and considerable detail. Intensive field verification, and frequent reciprocal exchange of practical experience between the office interpretation and field verification of the mapped natural units are necessary for the production of high quality maps. In spite of all the steps through which map production by LANDSAT imagery interpretation has to proceed, yet the time consumed in such proceedings is much less than that consumed through the application of previous techniques. Meanwhile, the synoptic and repetitive coverage of the natural units and phenomena in their various diversifications and manifestations represent particularly important advantages of the utilization of LANDSAT imagery in regional mapping.

The experience gained, during a period exceeding four years, in the application of LANDSAT satellite imagery interpretation in elucidating the groundwater conditions and related phenomena in Egypt is remarkable, especially when combined with the other hydrogeological and hydrological studies carried out on the pertinent water bodies exposed on the surface or hidden in the subsurface. Few examples are given in this communication concerned with the application of LANDSAT-1 imagery technique in studying regional groundwater conditions and manifestations in selected areas in Egypt.

WESTERN PERIPHERIES OF THE NILE DELTA

The distribution of groundwater in the Nile Delta is closely linked with the development of the geological history of the Delta from the Miocene times to the present, and with the influence of infiltration of the Nile water in the subsurface, Mediterranean Sea water intrusion and percolation of the rain water into the sedimentary cover of the concerned area.

The history of the Nile Delta since the Miocene as expressed in the delineation of the sediments covering the Nile Delta environs which range in age from Miocene to Holocene and the structural lineaments which bound the Nile Delta graben in its consecutive stages of development during the same time period has been elucidated through the application of LANDSAT imagery mapping techniques (El Shazly, Abdel Hady, El Ghawaby, El Kassas, Khawasik, El Shazly and Sanad, 1975).

The various aquifers dominating the Nile Delta and its western peripheries have been delineated on a regional scale by utilizing LANDSAT imagery interpretation in combination with the hydrogeological and hydrological data on the aquifers in question. The latter include leaky water in Holocene deltaic sands, free water in Holocene dune sand accumulations and Pleistocene detrital lime-

stone, sub-artesian water in early Pleistocene sand and gravel, unconfined water in early Pleistocene sand and gravel, semi-confined water in early Pleistocene sand and gravel (resulting from irrigation by Nile water passing through canals), and unconfined to semiconfined water in Neogene sandy facies (Figure 2). It may be noted in the same figure that the boundaries of the aquifers on the western peripheries of the Delta attain roughly a NW-SE trend which is almost the same direction as the main faults limiting the Nile Delta westwards during its tectonic development from the Miocene to the Holocene.

Apart from delineating the water-bearing geological units in the discussed area, LANDSAT-1 imagery interpretation has led to the mapping of units related to the salinization of water in the Nile Delta environments including salt crust and salty surficial materials, and marshes and sabkhas. All these expressions of conditions and manifestations of water are important in its exploration, exploitation and management in the Nile Delta and its environs where the greatest proportion of the population of Egypt are living.

SIWA OASIS AREA, WESTERN DESERT

It has been demonstrated by LANDSAT mapping techniques that the depressions in the northern Western Desert are greatly controlled by long faults and fractures of about E-W trend which extend for tens to hundreds of kilometers (El Shazly, Abdel Hady, El Ghawaby, Khawasik and El Shazly, 1976; etc.). In the meantime water ponds, springs and water wells distributed in the same area have been found to be spatially related in most cases to the above mentioned linear elements.

Figure 3 of Siwa Oasis located in the western part of the northern Western Desert illustrates very clearly the relation of the distribution of the water ponds to the delineated faults and fractures assuming an ESE-WNW trend and their intersections with those acquiring a NW-SE direction. Actually, one of the major ESE-WNW faults extends for a very long distance from the Siwa Oasis Depression westwards to the southern part of the Qattara Depression eastwards. In a comparable fashion the small depressions and water ponds extending from El Bahrein to Sitra are localized on the ENE-WSW faults and fractures.

Groundwater in Siwa Oasis is the only source of water supply available for domestic and irrigation purposes. The ESE-WNW faults delineated on the pertinent LANDSAT images by traversing the suitable water-bearing horizons, namely the Miocene, Eocene and Late Cretaceous-Early Carboniferous sediments, bring the groundwater to the ground surface or near it. In this way the groundwater is made accessible for consumption, either discharged by natural springs or man-dug wells of relatively shallow depths. The water ponds noted along the fault lines in Siwa Oasis Depression represent the water accumulating by groundwater discharge which is subjected in the mean time to evaporation and salt concentration.

Comparative features to those found in Siwa Oasis are noted in Kharga and Dakhla Oases Depressions where the faults and other lineaments mapped by LANDSAT imagery techniques have been found to control to a considerable extent the alignment of water ponds in this area located in the south Western Desert (El Shazly, Abdel Hady, El Kassas, Salman, El Amin, El Shazly and Abdel Megid, 1976).

MEDITERRANEAN SEA COASTAL ZONE

To the west of Alexandria and extending to the Egyptian-Libyan borders the Mediterranean Sea Coastal Zone is dominated by an important water-bearing geological unit of Pleistocene age termed Alexandria Formation. This unit has been delineated and mapped regionally along the whole Coastal Zone through the application of LANDSAT imagery interpretation techniques (El Shazly, Abdel Hady, El Ghawaby, El Kassas, Khawasik, El Shazly and Sanad, 1975).

Alexandria Formation has been differentiated into members constituted of detrital limestones (Figure 5), with or without indurated crusts, associated with clayey calcareous soils and a clay-gypsum member. The former members are essentially constituted of limestones of high permeability which possess cavities of various dimensions caused by karstification and other dissolution phenomena. These limestones represent an important aquifer in the Coastal Zone where the rain water is stored as large lenses floating on the intruding saline water of the Mediterranean Sea. The gentle topography combined with the relative softness of the limestones allow the roots of the cultivated plants to reach the water table attained by the fresh-brackish water lenses. Accordingly, the dispersed cultivation of the Coastal Zone is greatly dependent on the distribution of the outcrops of the mentioned limestones.

The capability of the detrital limestones to store water in their pores and cavities is enhanced by the configuration of the drainage lines which act as channels for runoff water. These either drain their water in closed lows or towards the Mediterranean Sea. The drainage map of a part of the Coastal Zone in the neighbourhood of El Alamein (Figure 4) shows the drainage pattern as delineated from LANDSAT images.

Furthermore, the clay-gypsum member of Alexandria Formation plays an important role in water logging and salinization in the Coastal Zone due to its impermeability and salt content. This unit has been delineated as islands outcropping in various parts of the Coastal Zone to the south of the detrital limestone exposures where they make the basal part of Alexandria Formation. It may be concluded from the above mentioned discussions that the mapping of the aquifers and aquicludes, as well as the drainage systems in the Mediterranean Sea Coastal Zone by LANDSAT imagery interpretation has given an overall regional picture of its groundwater potential.

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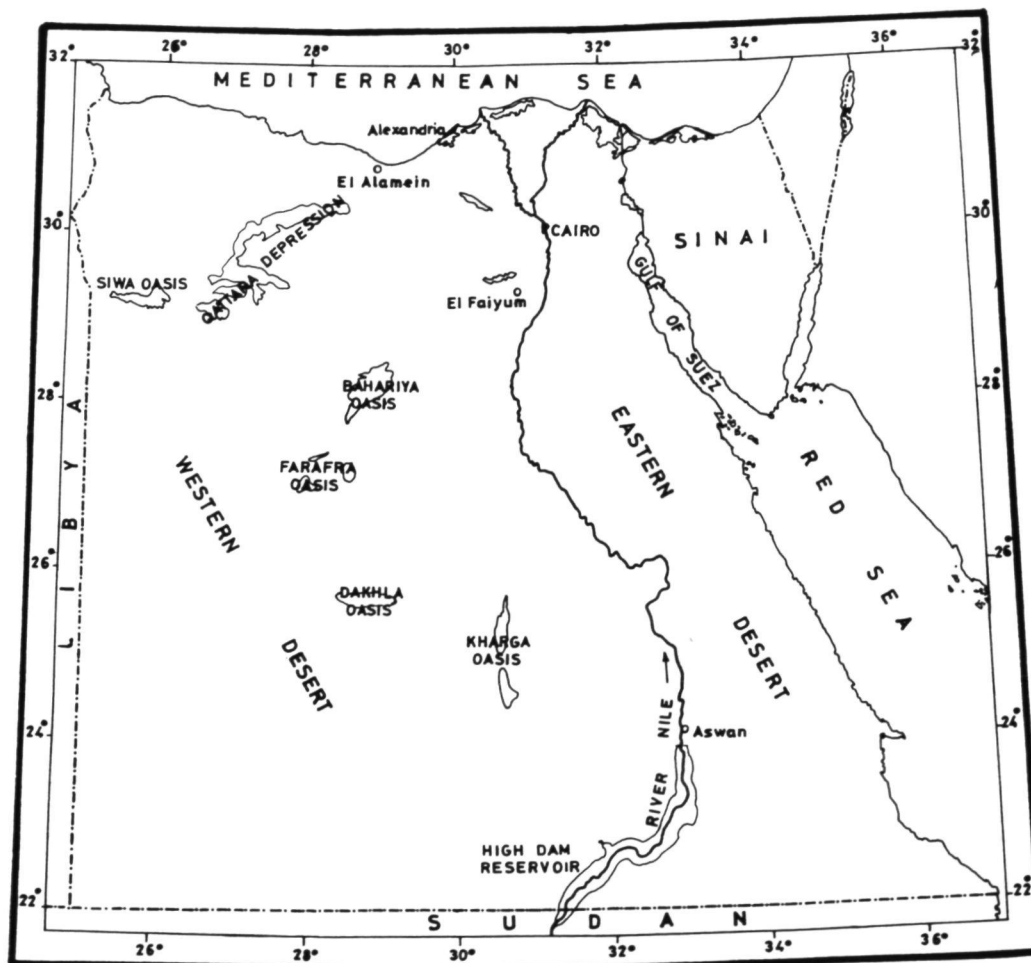
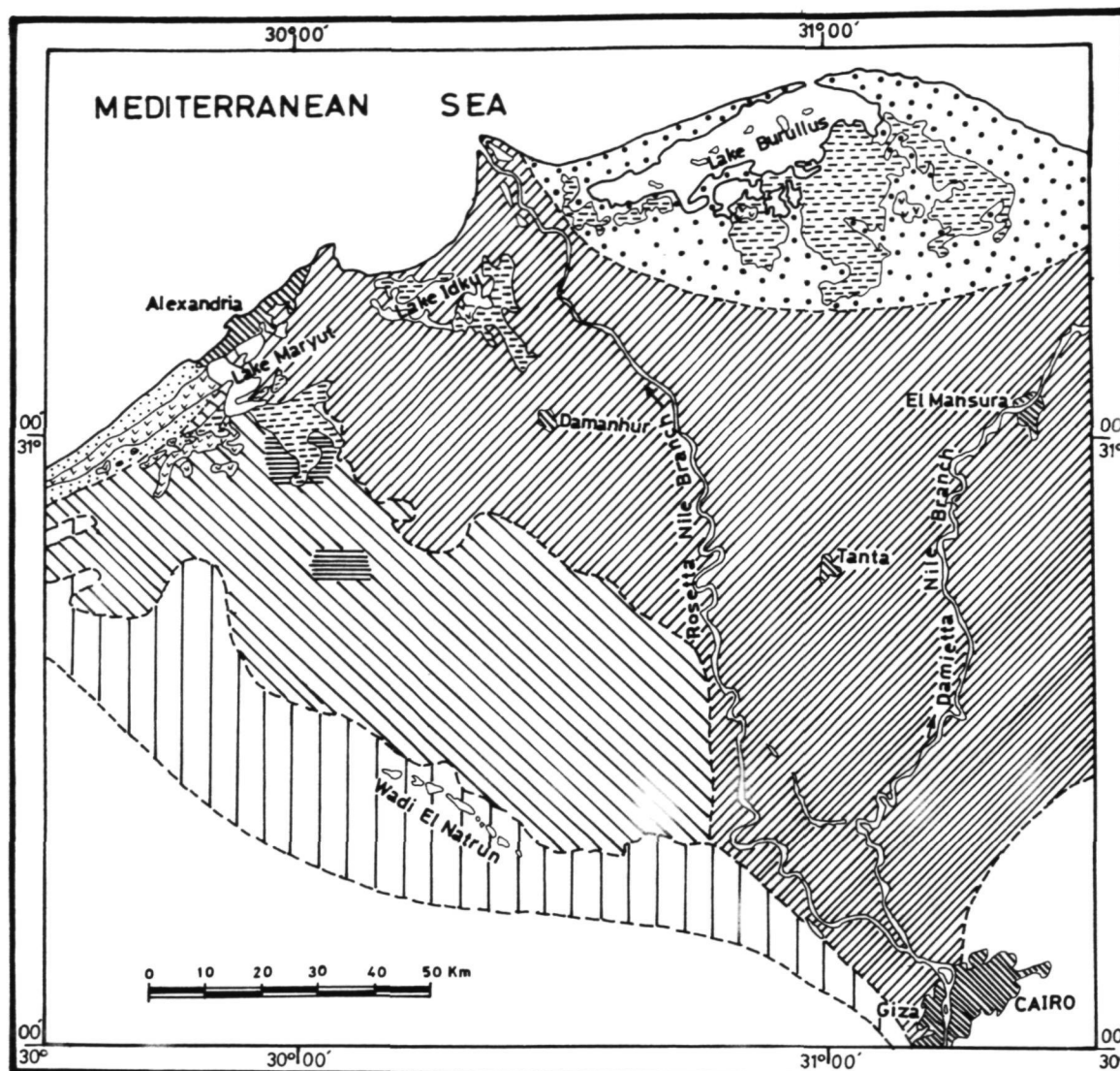


FIGURE 1. MAP OF EGYPT SHOWING CITED LOCALITIES.



LEGEND

-  LEAKY WATER IN HOLOCENE DELTAIC SANDS, UNDERLAIN BY SEMICONFINED WATER IN EARLY PLEISTOCENE DELTAIC SAND & GRAVEL
-  FREE WATER IN HOLOCENE DUNE SAND ACCUMULATIONS AND PLEISTOCENE DETRITAL LIMESTONE
-  SUB-ARTESIAN WATER IN EARLY PLEISTOCENE SAND AND GRAVEL
-  UNCONFINED WATER IN EARLY PLEISTOCENE SAND AND GRAVEL
-  SEMI-CONFINED WATER IN EARLY PLEISTOCENE SAND AND GRAVEL (RESULTING FROM IRRIGATION AND CANAL SYSTEM)
-  UNCONFINED TO SEMI-CONFINED WATER IN NEOGENE SANDY FACIES
-  SALT CRUST AND SALTY SURFICIAL MATERIALS
-  MARSHES AND SABKHAS
-  CITIES AND TOWNS

FIGURE 2. GROUNDWATER POTENTIAL MAP OF PART OF THE NILE DELTA AND ITS WESTERN PERIPHERIES.

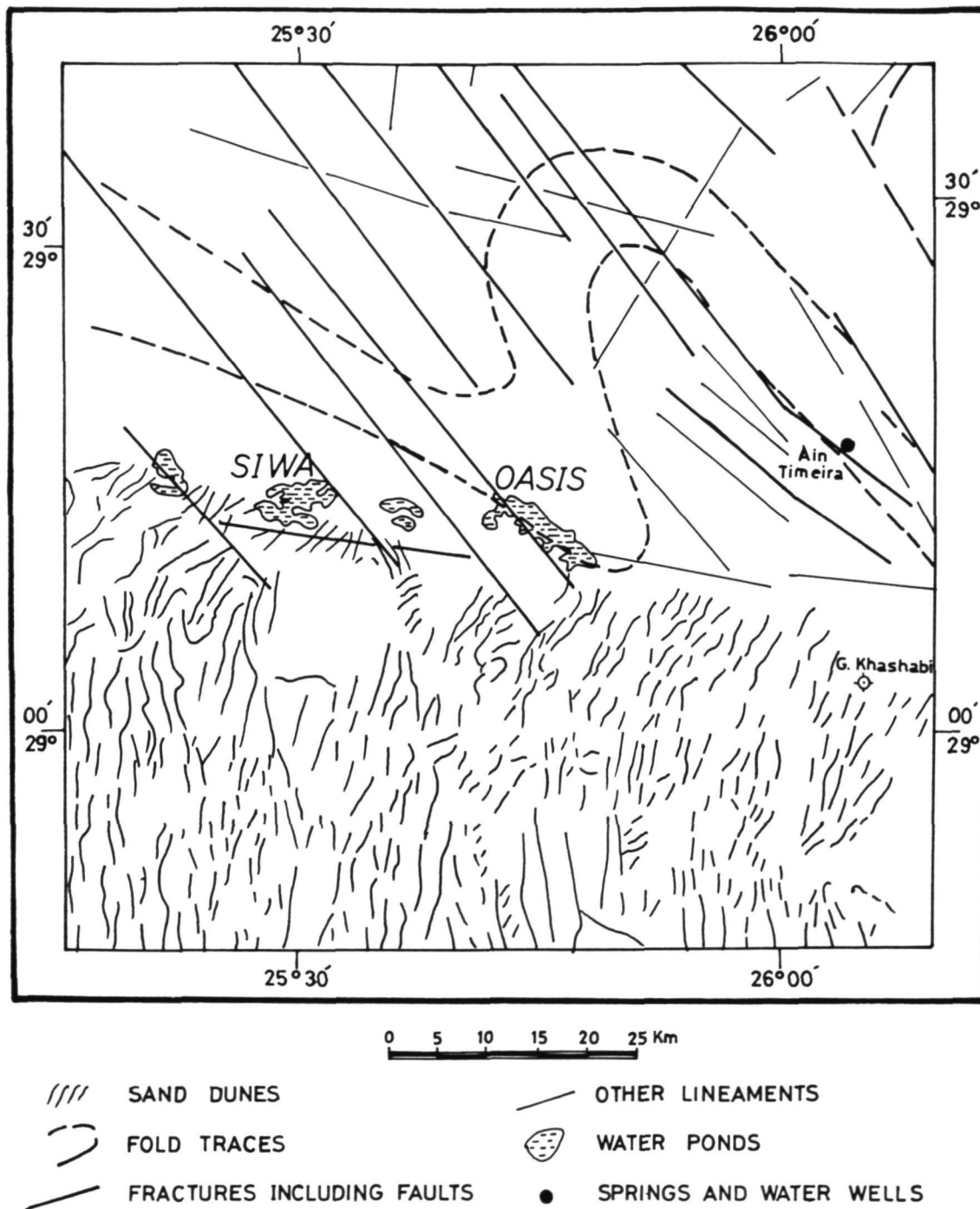
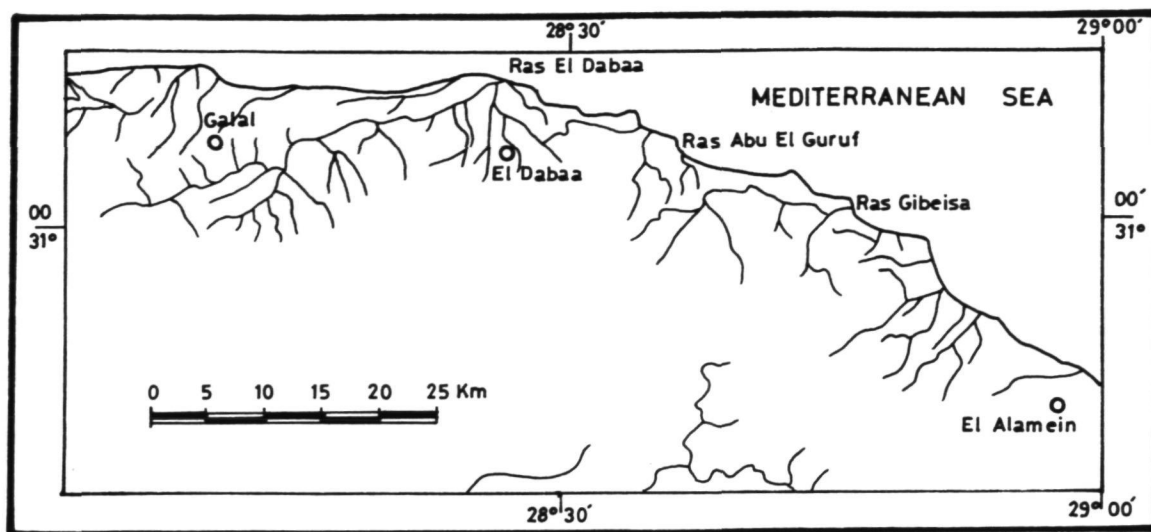


FIGURE 3. MAP OF SIWA OASIS ENVIRONS ILLUSTRATING RELATION OF STRUCTURAL LINEAMENTS TO WATER PONDS.

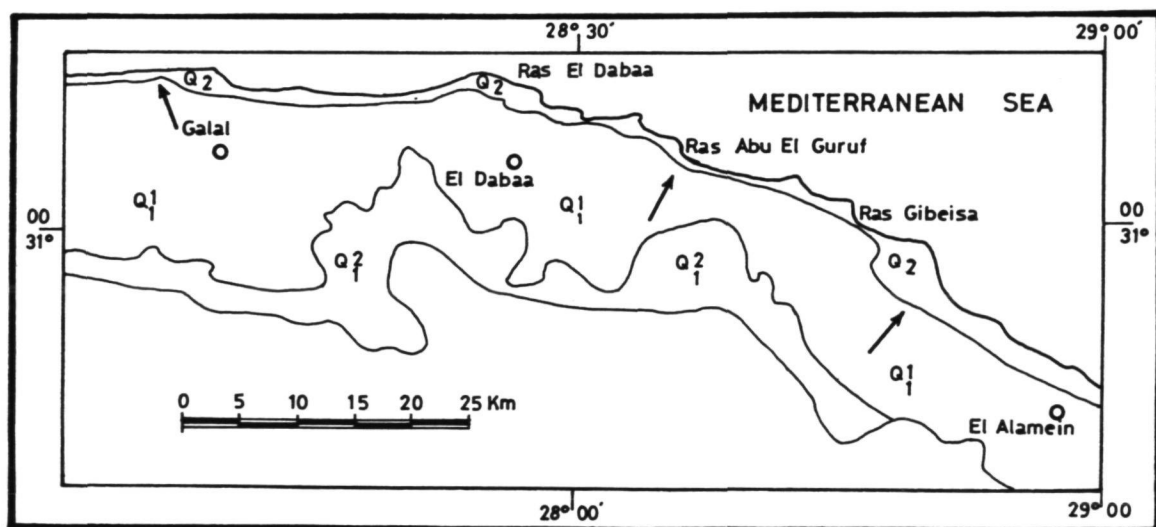


LEGEND

DRAINAGE LINES

SETTLEMENTS AND SMALL TOWNS

FIGURE 4. DRAINAGE LINES IN THE MEDITERRANEAN SEA LITTORAL AT EL ALAMEIN NEIGHBOURHOOD.



LEGEND

BEACH DEPOSITS

ALEXANDRIA FORMATION

Detrital limestone member with indurated crust

Detrital limestone member

DIRECTION OF PRESENT WATER FLOW

FIGURE 5. MEDITERRANEAN SEA LITTORAL AT EL ALAMEIN NEIGHBOURHOOD SHOWING THE WATER-BEARING ALEXANDRIA FORMATION.

OMTT

HYDROLOGICAL APPLICATIONS OF LANDSAT IMAGERY
OF THE
1973 INDUS RIVER FLOOD, PAKISTAN

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Summary

During August 1973, the Indus River Valley of Pakistan experienced one of the largest floods on record, resulting in millions of rupees worth of damage to homes, businesses, public works, and crops. Tremendous areas of lowlands were inundated not only along the Indus River mainstem, but also along a number of major tributaries. The exceptionally high floods were primarily due to intense and widespread rainfall, which resulted from the convergence of moist air currents from the Arabian Sea and the Bay of Bengal. Flooding extended throughout the length of the valley, but cloud cover obscured flooding in the northern part of the valley from satellite observation. Landsat imagery, however, made it possible to depict the extent of flooding within an area of about 500,000 km² from south of the Punjab to the sea.

The Indus River data were used to continue experimentation in the development of rapid, accurate, and inexpensive optical techniques of flood mapping by satellite begun earlier in 1973 for the Mississippi River floods. The research work on the Indus River not only resulted in the development of more effective procedures for optical processing of flood data and synoptically depicting flooding, but also provided potentially valuable ancillary information concerning the hydrology of much of the Indus River basin.

The only Landsat data used for the experimentation were 70mm film negatives in each of the four bands of 13 scenes collected by the Landsat multispectral scanner during the period of flooding from September 1-4, 1973, and the 70mm negative for band 7 only of the same area when imaged under "normal" conditions in December 1972. For the optical analyses the original 70mm negatives were reprocessed so as to provide improved contrast between water and wet surfaces and surrounding dry areas on the scene. This process resulted in a new set of "contrast-stretched" 70mm positive transparencies which were then used exclusively in the study.

A distinct improvement in contrast between wet and dry areas was achieved by this procedure. However, vegetation, moisture conditions, terrane types, and land use all have their effects on film density, and hence are not readily interpretable from single band data. Compositing of the data from the various bands by the use of color filters permits the investigator to separate features such as water and vegetation by color--a so-called "color-coding." Two special composites were prepared from the reprocessed positives: by compositing band 5 in blue light, band 6 in green, and band 7 in red, morphologic and geologic features are enhanced, and water detail is well preserved. Areas of standing water appear as black or blue, wet or saturated soils as brown, and barren soils as buff or gray. Vegetation is strongly subdued and appears in tones of yellow. This rendition revealed considerable information of hydrologic significance; including broken or leaking canals, probable areas of ground-water discharge, leakage under a dam, areas of ponded water following recession of the floods, in addition to delineating the flood boundaries.

A mosaic, consisting of another special spectral composite of cloud-free images, was also prepared to assist those involved in river basin planning. Band 4 was projected in green light, band 5 in blue, and band 7 in red. Although this rendition tends to reduce contrast in the desert and unflooded vegetated areas, it maintains considerable geologic detail in the flooded areas, and greatly improves flood plain detail in comparison to the "standard" band 4 blue, band 5 green, band 7 red composite.

A temporal composite that vividly color-codes the flooded area in red was prepared by projection of the band 7 flood image in green and the band 7 pre-flood image in red. A mosaic of these composites showed the distribution of flooding over most of the basin. This rendition also shows excellent differentiation between dry soil, saturated soil and standing water. Where there was water in both the dry scene and in the flood scene the area is black, and the pre-flood channels of the major rivers are thus depicted in black. Where flooding occurred in areas where no water was present in the dry scene, the flooded area in excess of 20,000 km² is depicted in red. The mosaic revealed flooding of about 2,500 km² of agricultural and desert land caused by a breach of the main channel of the Sutlej River upstream from the Panjnad head works.

N78-14583

APPLICATIONS OF LANDSAT DATA TO THE
INTEGRATED ECONOMIC DEVELOPMENT OF MINDORO, PHILIPPINES

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ABSTRACT

Landsat data is seen as providing essential up-to-date resource information for the planning process. As part of a USAID-funded grant, Landsat data of Mindoro Island in the Philippines was processed to provide thematic maps showing patterns of agriculture, forest cover, terrain, wetlands and water turbidity. A hybrid approach using both supervised and unsupervised classification techniques resulted in 30 different scene classes which were subsequently color-coded and mapped at a scale of 1:250,000. In addition, intensive image analysis is being carried out by the various Philippine government agencies in evaluating the images.

The images, maps, and aerial statistics are being used to provide data to seven technical departments in planning the economic development of Mindoro. Multi-spectral aircraft imagery has been collected to complement the application of Landsat data and validate the classification results.

INTRODUCTION

The purpose of USAID's Remote Sensing Grant Program is to support establishment of an indigenous capability in developing countries to use appropriate remote sensing technology. In instituting the Grant Program AID recognized that developing-country planners and scientists are frequently in the best position to determine their country's priority information needs and in what way remote sensing is likely to contribute to national development.

The Bureau of Mines of the Philippines' Department of Natural Resources submitted a proposal to USAID to use remote sensing data in connection with large-scale integrated economic development program for the Island of Mindoro. This proposal was competitively selected and subsequently approved for funding in late 1975. In 1976 the Philippines grantee received an award of \$20,000 and technical assistance from the Environmental Research Institute of Michigan (ERIM), AID's contractor for administering these grants.

As a small part of the Philippines' Grant project ERIM processed Landsat data in preparation of three thematic image-maps of Mindoro. Herein is a brief description of that effort in support of the Mindoro project.

The purpose of producing thematic image-maps was to determine the nature and accuracy of the information available from Landsat data of the Philippines. While it is recognized that manual image analysis techniques provide highly useful land cover and water quality data, computer compatible tapes may offer the greatest opportunity for systematic and quantitative analysis. This task was intended to test the use of digital Landsat data for large-area development planning.

MINDORO ISLAND

Mindoro is the seventh largest island in the Philippines and comprises 10,347 square kilometers (3,995 square miles) of hilly or mountainous terrain and narrow coastal lowlands. It is located due south of the Island of Luzon and 123 kilometers from Manila. Mindoro has a population estimated at 300,000 people, many of whom belong to tribal groups with fairly primitive methods of fishing and shifting agriculture. Development has lagged on this island owing to the relatively small proportions of good level agricultural land in relation to the extensive areas of forested mountain slopes. However, it is clear that with comprehensive resource development Mindoro could become more prosperous. It is rich in primary forests, aquatic resources, and possibly economic minerals. Forestry, fishing, mining, and agriculture are economic activities which could benefit from a more accurate knowledge of Mindoro's resources.

Mindoro is positioned such that the entire island is usually recorded on a single Landsat image frame (see Figure 1). The first satellite picture of the island was obtained in the fall of 1972 and subsequently the island has been imaged more than a dozen times on successive passes of Landsat. Cloud cover is always a problem in viewing Mindoro because the northwest-southeast trending mountain ranges are perpendicular to the directions of the moisture carrying monsoons. Clouds usually cover either the northeastern half or the southwestern half of the island. Only occasionally, during the inter-monsoon period, is Mindoro largely free of cloud cover. Landsat I data collected on December 23, 1972 showed relatively few clouds; these data were used for machine-processing.

PROCESSING PROCEDURES

The objective of the machine-processing was to produce thematic maps and areal statistics which would assist in integrated development planning. Specifically, different terrain and cover classes were selected and mapped at a scale of 1:250,000. It was felt that the available satellite information could be lumped into five general classes on the basis of spectral characteristics: (1) forests (including primary and secondary), (2) agricultural lands, (3) natural aquatic vegetation (swamps and marshes), (4) geologic structure and drainage patterns, and (5) coastal water quality (primarily turbidity). On the maps produced, forests and aquatic vegetation were shown on the same map, and geologic structure and water quality were combined -- resulting in a total of three maps.

The ERIM Multivariate Interactive Digital Analysis System (MIDAS) was used for this task. The MIDAS special-purpose computer provides an interactive, user-oriented capability for producing thematic maps derived from Landsat multispectral data. In this machine, the parallel digital implementation capabilities of the processor are combined with a mini-computer to achieve near-real-time operation coupled with multiple preprocessing functions and color displays. The data classifier is designed to perform a one pass maximum-likelihood decision with a priori probabilities, assuming multi-model Gaussian multivariate spectral distributions. The output of this classification process is a geometrically-rectified color-coded hard-copy image-map. These maps may be produced at any convenient scales; 1:250,000 for this large-area project.

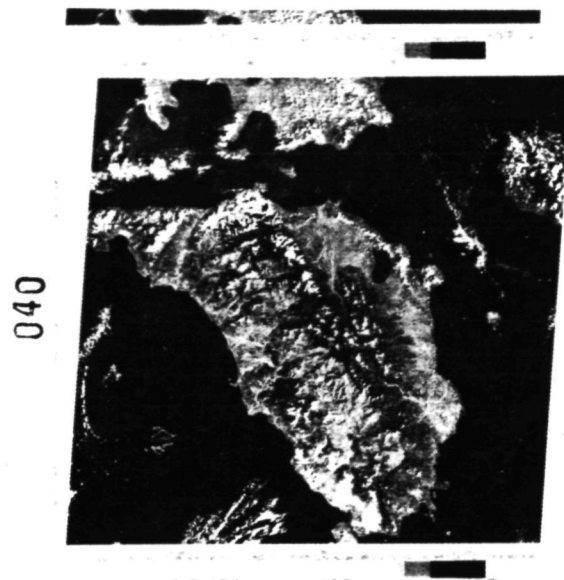


FIGURE 1. Landsat Image of Mindoro Island (Band 5)

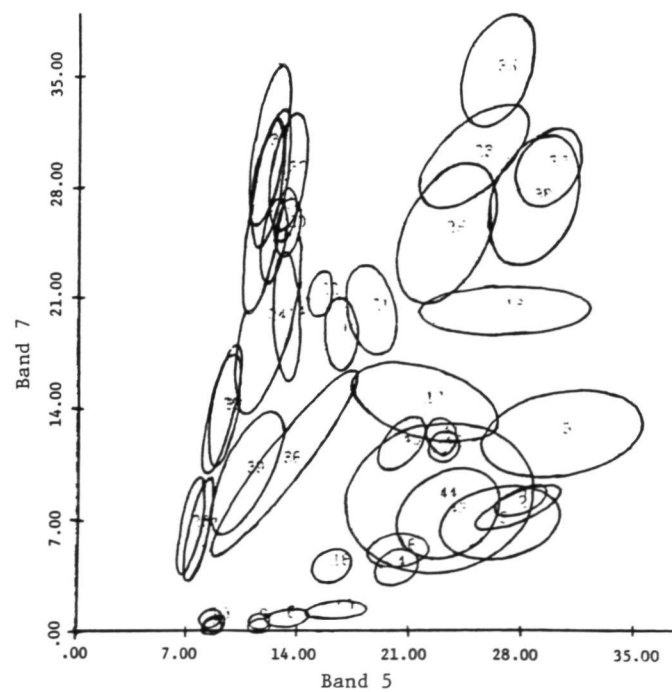


FIGURE 2. SIGNATURE VALUES IN LANDSAT BAND 5 AND BAND 7.
ELLIPSES REPRESENT ONE STANDARD DEVIATION FROM MEAN VALUES.

SIGNATURE SELECTION

Spectral signature selection for classifying Landsat MSS data is the key to successful processing results. Therefore, careful attention was given to data analysis directed at appropriate signature selection.

Utilizing the forestry, soil, crop, wetland, and bathymetric information supplied by the Bureau of Mines, some 43 different signature locations ("training sets") were selected. The spectral characteristics of such features as primary forest, secondary forest, beach, stream courses, rice, marshland, coconuts, other crops, and turbid and clear water as nearly as could be identified were obtained in all four Landsat bands. These were described by their mean values and covariances in each band. Subsequently, these characteristics were plotted as one-standard deviation ellipses for two band combinations. One of these is shown in Figures 2 (Band 5 vs Band 7). As can be seen, considerable overlapping occurs between ellipses, indicating that there is a spectral continuum associated with the data and that it is not possible to selectively eliminate all overlapping and consequent probable misclassification of features. (Other band combinations showed greater overlapping.)

In addition to the training-set selection (for supervised classification), data clustering, for unsupervised classification, was also performed. The clustering procedures allow an even, non-overlapping arrangement of signatures (see Figure 3) but considerable uncertainty concerning signature identification.

Finally, spectral signatures selected for data classification comprised a combination of subsets of both the known training set signatures and the cluster signatures. Training-set signatures of known scene classes were used where possible, but for spectral conditions not covered by some selected training set, cluster signatures were used to "fill-in". Twenty-nine different signatures were subsequently classified.

CLASSIFICATION RESULTS

The twenty-nine signatures selected were thought to represent almost the entire spectral range of the Mindoro data. Only 1.4% of the data was subsequently left "unclassified" on the basis of a maximum likelihood ratio decision rule implemented by the computer.

Essentially the computer compared the recorded spectral characteristics of each and every picture element (pixel) and determined which of the twenty-nine signatures, if any, is most similar. Therefore, each of the pixels were assigned to one of twenty-nine different classes or an "unclassified" class if it was very different. In doing so, the computer tabulated the number of pixels identified in each class and the total area represented by each.

Forty percent of the total area was classified (16,370 sq km) as water and 3.7% was cloud and cloud shadow. Of the land area classified 21% (2,043 sq km.) is forest, 38% (3,750 sq km) is cropland or aquatic vegetation. Some misclassification occurred due to the overlapping spectral characteristics of certain features -- for example, secondary forest appeared similar to certain types of cropland and lowland rice appears similar to wetland.

MAP GENERATION

In addition to the statistics generated by the data classification procedure, the final product of this task was the production of three thematic maps wherein different terrain classes and combinations of classes were color-coded. It is not possible to clearly display 29 different colors, representing 29 different terrain classes at a scale of 1:250,000. In general, the eye is able to discern about 10 different colors when they are complexly interwoven

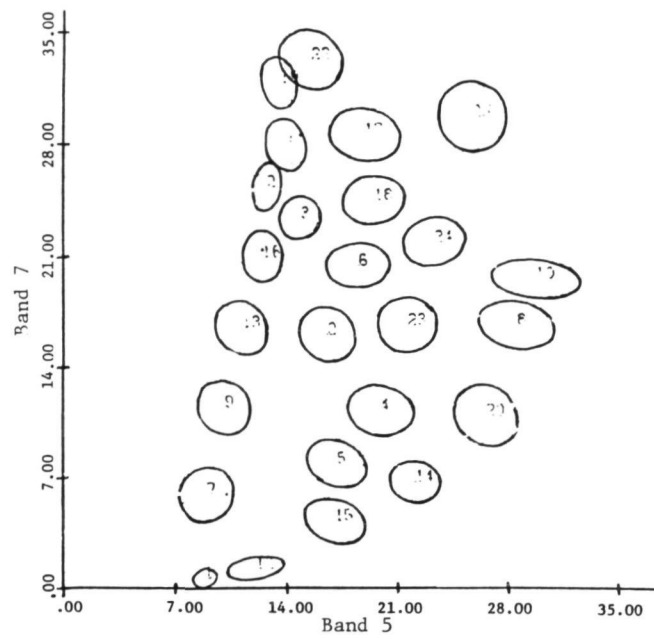


FIGURE 3. UNSUPERVISED CLUSTER VALUES IN LANDSAT BAND 5 AND BAND 7. ELLIPSES REPRESENT ONE STANDARD DEVIATION FROM MEAN VALUES.

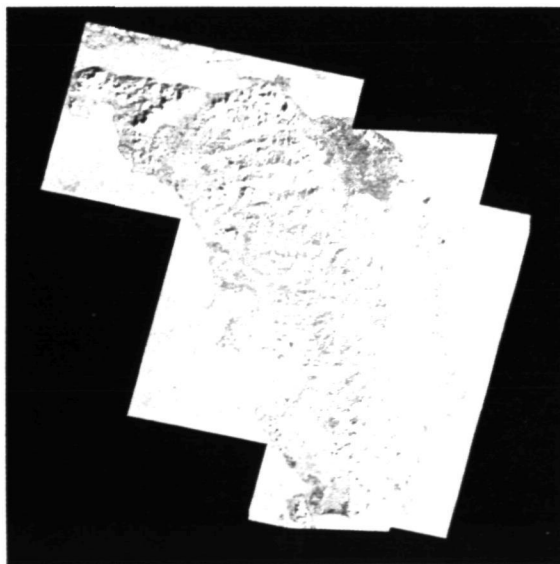


FIGURE 4. ERIM MIDAS CLASSIFICATION MAP SHOWING TOPOGRAPHIC STRUCTURE.

in a detailed map. Using the 29 different classes, colors were selected to show spatial patterns associated with forests, topography and water quality, and cropland and wetland on separate image-maps. While the agriculture and forest maps were conventionally represented, the image map showing topography was somewhat unique. Signatures for north and west facing slopes were colored violet in contrast to the south and east slopes which were gray (see Figure 4). Solar illumination differences resulted in different signatures for these slopes (the sun elevation was 42° and azimuth, 139°).

MAP EVALUATION

Using the ground truth information supplied by the Bureau of Mines some preliminary comparisons with the MIDAS map results showed the Landsat data to provide greater spatial detail than is possible to obtain using simple manual techniques. The results also demonstrate that the illumination of slopes varied greatly with orientation and that several signatures were required to map the same features. For example, primary forests on northern and western slopes appeared quite different from similar forests on eastern and southern slopes. Some areas indicated on the ground truth maps as primary forest did not appear on the Landsat forestry map and need to be investigated further. Similarly extensive agricultural areas show complex spectral patterns indicating a variety of crop and cultivation conditions. Aerial photography and ground observations are being used to evaluate the accuracy of specific classifications.

CONCLUSION

The Republic of the Philippines is an archipelago extending for 1,100 miles and is composed of 7,100 islands and islets. With its burgeoning population of 46 million people and increasing need to develop its resources, the Philippines is looking, in this and other projects, to the use of Landsat data for resource information required for sound development planning. This space-acquired information can then be combined with other information (such as aircraft and/or ground survey data) through a planning or management system. Ultimately this information will be supplied to a decision-making institution which can use the information for development planning purposes.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF AN INTEGRATED DATA BASE FOR
LAND USE AND WATER QUALITY PLANNING

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INTRODUCTION: CREATING UNDERSTANDING

Basic knowledge about the way natural and human systems function and relate to one another is an essential ingredient in charting the best course of action to make choices that affect land and water. The recent Toledo Metropolitan Area Council of Governments (TMACOG) Areawide Water Quality Management Planning Program (PL 92-500, Section 208) has made it possible to gather and analyze information. This, in turn, has led us to a more complete understanding of our local environment than was ever before possible. To help understand the role played by different land resources in water quality management we created a computer based data system. The Land Resource Information System (LRIS) allows data to be readily retrieved or statistically analyzed for a variety of purposes. It is specifically formatted to perform coordination of water quality data with the co-occurrence of land resource factors such as soil characteristics, land use, hydrology, topography, etc.

Our new understanding of the region gained through the use of LRIS has gone well beyond the initial purpose of assessing water quality conditions. The land use and natural features information has provided a well defined starting point for a systematic evaluation of proposed land uses, transportation, housing, and other public investments. It has laid the foundation for a comprehensive and integrated approach to many different planning and investment programs presently underway.

1. LAND RESOURCES INFORMATION SYSTEM SPECIFICATIONS

LRIS has been designed:

- 1) to take advantage of existing data sources
- 2) to provide the detail of information necessary to assess the impact of land use on water quality
- 3) to provide a permanent data base for future comprehensive planning studies.

Size of Study Area: 5200 KM² (2006 Mi²)

Location of Study Area: 6 Counties on the south shore of Lake Erie in Northwest Ohio and Southeast Michigan.

Data Collection System: Grid Cell and point, unaligned random sample

Coordinate System: Universal Transverse Mercator Projection

Cell Size: 4 Hectares (9.88 Acres) (139,538 cells in the study area)

Source Data:

- * 1:50,000 Aerial Photography
- * USGS 7-1/2 min. Topographic Maps
- * County Soil Surveys

Main Data File Content:

- * Land Use - 36 categories of land use and up to 12 figures of ancillary data for each cell/point location
- * Soils - Mapping unit from detailed soil survey
- * Topography - 5' Contour Interval
- * Hydrological location - Minor watershed
- * Political location - Minor civil division
- * Socio Economic location - Traffic zones and census tracts

Auxilliary Data Files:

- * Soils physical properties
- * Water resources data

Output Modes:

- * CRT Display (working)
- * Ink Jet Printer Maps (working)
- * Digital Laser Printer Maps (permanent, printable)
- * Calcomp/Symmap Maps

Data Analysis:

- * Co-occurrence of natural land resource features
- * Land Capability
- * Land Use Suitability
- * Land Use Policy Impact Analysis

2. APPLICATION OF LRIS

2.1 WATER QUALITY MANAGEMENT PLANNING

The use of LRIS in the assessment of water quality problems and the design of solutions falls into two broad categories. One is Non-Point Source (NPS) oriented and the other focuses on pollution from Point Sources (PS). The NPS problem in the TMACOG region is dominated by agricultural runoff. Fertilizer runoff from agricultural lands contributes nutrients to the water and initiates a sequence of events which degrades water quality. The second category, PS problem, is dominated by Public Sewage Treatment Plants (STP's) and home or on-site sewage systems.

2.1.1 AGRICULTURAL RUNOFF POLLUTION ABATEMENT

Runoff from agricultural land has been identified as a principal source of sediment and nutrient pollution of Lake Erie. Approximately 83% of

the total transport of the nutrient phosphorus during 1975 came from some source other than the discharges of municipal sewage treatment plants. Numerous investigations have shown that the sediment and nutrient content of direct runoff from agricultural land is sufficient to account for most of this non point source pollution. Other major categories of non point source pollution include runoff from urban land, atmospheric input (principally related to wind erosion at distant locations) and demineralization of inorganic materials in soil and decomposition of organic detritus.

The most easily identifiable problems include rill and gully erosion, but in Northwest Ohio sheet erosion, the progress of which is nearly invisible to the eye contributes the greatest portion of the sediment transport. Sheet erosion is caused by the impact of falling raindrops on bare soil surfaces. The regions glacial clay soils are highly productive, and nearly 90% of the land area is devoted to the production of row crops, principally corn and soybeans. Fall moldboard plowing is the dominant tillage practice, and leaves the land barren of any protective cover for 8 to 10 months of the year.

Recent studies have shown that sheet erosion can be reduced to nearly zero by the use of a cropping practice called No-till, which can leave the land with almost complete ground cover between harvesting and planting. Other systems of reduced tillage produce less dramatic reductions in sheet erosion, proportionate to the amount of surface coverage.

Research studies which have been done at the Ohio Agricultural Research and Development Center have proven the utility of no-tillage and reduced tillage as economically feasible crop production systems. This work has also identified the soils of Ohio on which these new techniques will be practical, since not all soils are suitable for reduced tillage practices without significant reduction in yield.

If an agricultural pollution abatement is to be built around around a reduced tillage program it is necessary that suitable soils be identified. A general classification of soils groups them into the following categories: 1) suitable for no-tillage, possible increased yields; 2) suitable for no-tillage with improved subsurface drainage; 3) unsuitable for no-tillage; 4) suitable for no-tillage under certain circumstances; and 5) undetermined suitability. Further work with these classifications has been done to define the economics of the systems and the suitability of other forms of reduced tillage. This analysis places groups 1 and 2 into a suitable for no-tillage class, group 4 is suitable for minimum tillage, and groups 3 and 5 are not considered for any form of reduced tillage.

The LRIS was used to identify, map, and summarize the areas which were suitable for reduced tillage systems. Overall, about 60% of the total TMACOG area was found to be in categories 1, 2 and 4. A Calcomp plotter was used to draw a map of the entire 5200 square kilometer area showing areas of cropland in each of the 5 categories. This map will be used in a technical assistance program to help farmers decide whether or not a reduced tillage practice would be suitable for their cropping system.

In order to determine the effectiveness of widespread adoption of reduced tillage systems in reducing sediment and phosphorus loading to Lake Erie, the LRIS was again used to develop the soils data into a format that could be used with the Universal Soil Loss Equation. Estimates of existing gross erosion and total phosphorus transport were calculated for comparison with total transport which would result when appropriate no-or-minimum tillage systems were in operation on 100% of all cropland where those systems could be applied with no seriously adverse economic effect. The analysis indicated that sediment delivery could be reduced by 41% and total phosphorus by 26%.

2.1.2 POINT SOURCE POLLUTION ABATEMENT PROGRAM

There are a number of intervention points in the planning, design, and operation of treatment facilities to affect their impact on water quality. By far, the most cost effective is at the planning stage. At this stage, the size and location of treatment plants and the collection system are determined as a function of population growth and those factors which affect its spatial allocation. Historically such decisions are determined through a mix of perceived trends, local politics and real estate developers. LRIS introduced a new dimension, the environment. Physiographic features and regions are mapped for the facility planning area using LRIS. Each feature is characterized in terms of development attributes such as: excavation, drainage, grading, etc. Specific capability functions have been coded into the LRIS. Hence, it is possible to map an area's capability for residential, commercial/industrial development or for underground facilities.

The LRIS environmental capability maps can be overlaid with local land use maps, trend growth maps and existing land use maps to form a readily understood graphic evaluation procedure. Proposed facility plans can then be evaluated according to their compatibility with the soils and geology of the area, minimizing the pollution potential from a facility.

2.1.3 HOME SEWAGE SYSTEMS

The combination in the TMACOG area of extensive rural development, the predominance of soils unsuitable for septic systems, and a network of drainage ditches, makes for a condition called "Black Water". Poorly functioning on-site disposal systems drain into local ditches causing poor water quality and a potential health hazard. LRIS was used to map a septic tank capability for the region based upon basic soils data. Local health officers and sanitary engineers can now use the map to guide rural development, avoiding unsuitable areas.

2.2 COMPREHENSIVE LAND DEVELOPMENT PLANNING

LRIS can also assist in the integration of the many categorical planning programs, water quality, housing, transportation, etc. into a comprehensive region-wide planning program. One way it can do this is by the Urban Service Area concept. Highway congestion, the availability of nearby parks and recreation facilities, a wide choice in housing, convenient shopping, commercial, cultural, and entertainment centers, and a viable local economic base -- these are all very strongly affected by public investment decisions. The Urban Service Area concept is a means for managing public resources so as to maximize the use of existing infrastructure, and insure a coordinated public investment strategy consistent with environmental, economic and land use policy objectives. LRIS provides the ability to delineate and evaluate these service areas.

In delineating the service area, the first step is to measure the carrying capability of the area presently served by sewer and water. LRIS can be used to identify urban open space and evaluate it for its development capability. As a guide to expansion, areas of potential conflict between development and agriculture are identified on an LRIS generated map. This, along with the other land use and environmental capability functions, is used as a part of a methodology to identify areas suitable for expansion.

3.0 IMPLICATIONS FOR RESOURCE MANAGEMENT SYSTEMS

The fundamental task of any public agency is the effective management of public resources. A pre-requisite for sound public investment decision-making is local capability to solve problems and implement solutions. This requires the existence of a comprehensive management structure as well as the necessary data, tools and analytical procedures.

3.1 NATURAL REGIONS AND FEATURES

The use of LRIS in the delineation and functional characterization of natural areas will have long term implications for the management and institutional frameworks governing sub-state units of government.

City and county lines have a long tradition, are firmly implanted in the legal/institutional structure of local government, and are part of each resident's sense of place. Metropolitan regions, based largely on trip patterns, also enjoy an identity in the minds of their inhabitants which may or may not be reflected in the local governmental structure.

The least identifiable areas are those which are based on common natural features. River basins and unique or sensitive environmental areas are usually distributed among many political jurisdictions. Sometimes citizen/environmental groups who may share a common concern for such an area may form a link among the many local governments and agencies. But such links often breakdown, lack of interest, membership continuity, and their weight and standing with local officials can change with the next election.

The challenge, then, is to integrate natural areas as management areas into the local institutional structure. Here is where LRIS has proven invaluable. It has allowed us to identify such areas, and through various graphic output devices has provided us with the means to communicate the concept of natural areas in a meaningful way.

TMACOG's Water Quality Management Plan has integrated natural areas into its proposed management structure. Specific programs regarding home sewage systems, agricultural runoff abatement, sewer service facility evaluation, comprehensive land use planning, all embody the concept of natural areas as management areas.

TMACOG has identified physiographic regions and features based on LRIS analysis of soils and geologic data. These are basic land resource units, each characterized by a unique set of opportunities and constraints on their use.

These areas provide the basis, not only of water quality planning, but provide input to local land use decisions. It is the aim of ecological planning to successfully integrate human activities with the natural system. To accomplish this we have described the region according to the characteristics that influence human activities and, in turn, how those activities would have to be modified in order to successfully adapt to those same natural characteristics. The activities investigated include: residential development, intensive development such as industry and agriculture and open space.

Each physiographic unit is analyzed for activities relevant to development such as clearing, excavation, soil stability, on-site sewage disposal, etc. The result is a guide which identifies those areas propitious for development, and also outlines the necessary adaptation if development takes place. For example, detailed knowledge of the specific limitations of a particular natural unit (e.g., Sand Hollows) can be translated into performance zoning available to local government to guarantee the successful adaptation of any development. The advantage is that unlike conventional zoning which is usually expressed in terms of a single type of use, performance zoning is expressed in terms of the natural characteristics of the site and allows a variety of uses as long as it conforms with the required adaptations.

3.2 SURFACING ISSUES AND ARTICULATING THE LOCAL VIEW

One consequence of analyses such as those described above is that issues, problems and potential conflicts surface early. The purpose of planning is not

necessarily to resolve conflict, rather its function is to spotlight potential problems and test alternative solutions. The assumption is that it is less expensive to do so in the abstract, before the concrete has a chance to set.

Another major benefit of the LRIS based analytical process is its use as a communications device. This is where the alternative graphic output modes of LRIS are very useful. It has been our experience that the immediacy of a color land use map or a residential capability map increases the impact of the information on elected officials and other public policy decision makers.

LRIS makes it possible to express the community and regional viewpoint in a organized and well structured context. This greatly enhances its chance of being heard and influencing federal decisions. In the long-term the cumulative effect could be to incorporate the common concern of the region into federal policy formulation, possibly reversing the trend of federal encroachment on local government decision-making.

METEOROLOGICAL SUPPORT FOR REMOTE SENSING PROGRAMS

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ABSTRACT

Many earth-oriented remote sensing spacecraft and aircraft programs are affected by the presence of clouds. Like aerial photography, they require clear or mostly clear skies. To cope with the cloud problem, the National Weather Service through its Spaceflight Meteorology Group (SMG) of the Space Operations Support Division makes cloud cover forecasts, as part of its specialized weather service for various NASA remote sensing and other programs. Forecasting requirements vary in time from a few hours out to several days and in areal extent from a particular locality to nearly global in coverage. Depending on the stage of program development, some remote sensing programs may involve special climatological studies for planning purposes or need ground-truth data for comparison with remotely sensed information.

This paper will discuss briefly the importance of computer and weather satellite products to the SMG meteorologist and describe the nature of SMG's weather support of past, present, and future remote sensing programs. Hopefully, as a result of this paper you will agree that when the weather forecaster is an active participant in specific programs, the chances of success are greatly improved.

1. INTRODUCTION

Remote sensing programs differ greatly as to sensors used; i.e., cameras, microwave radiometers, multispectral scanners, laser profilers, scatterometers, etc.. A program may involve a single sensor or a combination of sensors. The purposes of the many programs are even more varied than the kinds of sensors involved. Yet, regardless of the diversity in sensor types and program objectives, there is a common factor - the weather, which in some way affects all of them. The presence of clouds interferes with many earth-oriented remote sensing programs from spacecraft and aircraft. Usually, clear or mostly clear viewing conditions are required. Aerial photography, of course, is a very old example of an operation which required clear skies and good visibilities.

To cope with the cloud problem, the Spaceflight Meteorology Group (SMG) makes cloud cover forecasts in support of various NASA remote sensing and other programs. Forecasting requirements vary in time and areal extent; in time, from a few hours out to 5 or 6 days and in areal extent, from a specific locality to almost worldwide coverage.

Since 1960 the SMG has provided operational weather support for all NASA's manned space missions - Mercury, Gemini, Apollo, Skylab and the joint United States-Russian Apollo-Soyuz Test Project. Until 1972, when we began daily global cloud cover forecasts for the Earth Resources Technology Satellite (ERTS, now Landsat) Program, our experience with downward-viewing sensing experiments had been with those involving the Manned Space Program and related photography from NASA aircraft. The Landsat Program is an excellent example of how the meteorologist uses remotely sensed information from one program; namely, weather satellite cloud imagery, to support another remote sensing program - NASA's Earth Resources Program. With the launch of Landsat-C in September of this year, both daytime and nighttime global cloud cover forecasts will be required because of the added night sensing capability.

Of a different nature was our involvement in the Geodynamics Experimental Ocean Satellite Program (GEOS-3) and the Tropospheric Research Technology Operating Plan (TRTOP). For GEOS-3, conventionally derived sea state conditions - both those manually prepared and computer generated, were provided for comparison with the data obtained by the GEOS-3 radar altimeter. For TRTOP, satellite derived relative cloud cover climatology was used as an aid in selecting over 100 worldwide ground-truth monitoring sites, of which detailed cloud climatological statistics were prepared from standard weather summaries for some 60 of the initial sites.

Presently, other than the Landsat Program, SMG supports part of NASA's Airborne Instrumentation Research Program, which like Landsat involves experiments in almost every scientific discipline associated with the earth and its environment. Also SMG makes daily forecasts of various weather parameters for the Jet Propulsion Laboratory which is developing a weather model to provide near real-time predictions of weather induced X-band communication degradation at NASA Deep Space Network tracking stations in support of the forthcoming Mariner-Jupiter-Saturn '77 project.

Lastly, there is the upcoming Shuttle Era with six Orbital Flight Test missions to begin in 1979. On two of these missions earth viewing activities are planned and probably will require support similar to Skylab.

The above summation of SMG's participation in past, present, and future remote sensing programs serves to illustrate the diversity of the various programs and yet there is always the weather with which to contend. It is difficult to conceive how weather support for today's various remote sensing programs would be possible without the aid of modern computers and meteorological satellites. Lacking the information provided by these important tools, weather support for remote sensing programs, particularly those having nearly global requirements, would revert to little more than mere climatology for much of the world. Fortunately, developments in these areas have pretty much kept pace with the changing needs of the nation's manned and unmanned space programs during the 1960s and 1970s.

In what follows the importance of computer and meteorological satellite products to today's meteorologist will be discussed briefly and the nature of SMG's weather support for various remote sensing programs will be described.

2. IMPORTANCE OF COMPUTER AND METEOROLOGICAL SATELLITE PRODUCTS IN WEATHER SUPPORT OF REMOTE SENSING PROGRAMS

Before the development of electronic computers in the 1940s, weather forecasting was very much an "art" like the early days of flying when they flew by the "seat" of their pants. Forecasting skill was largely related to one's experience and based primarily on methods of short term extrapolation and recognition of weather patterns including historical knowledge of their most likely sequence of subsequent change. But, the development of the computer in the early 1940s changed all of that.

Electronic computers make it possible to use theoretical models of the actual atmosphere and after myriad mathematical computations, produce analyses and prognoses showing the present and future locations and development of pressure systems (and much other useful information) to aid the forecaster. The present global and hemispheric Primitive Equation models furnish forecast guidance with useful accuracy out to 5 or 6 days. One experimental model under evaluation shows some skill on forecasts out to 15 days.

Whereas, computer programs furnish the forecaster information on the movement and development of pressure systems, it is the meteorological satellite information in the form of cloud photographs that provides the most reliable depiction of the clouds and cloud systems. This fact was immediately apparent from cloud photographs taken by the first meteorological satellite (TIROS 1) launched in 1960.

Satellite cloud photographs are unique in that they provide pictorial representation of the integrated effects of the physical processes at work as evidenced in the clouds and cloud system. Such a perspective permits the meteorologist to deduce many important details regarding weather features of almost every scale as well as something about their interrelationships. In fact, meteorological satellite photographs provide the forecaster an overview and insight not possible by any other means. Many synoptic features, such as, cyclonic storms, fronts, jet streams, ridges, troughs, and vortices are often easily discernable and of great value in weather

analyses and short range forecasting.

Current NOAA polar orbiting satellites provide twice daily global coverage (about 9:00 a.m. and 9:00 p.m. local time). Satellite cloud depictions are particularly helpful in making weather analyses for approximately 70 percent of the earth's surface which has a very limited number of surface and upper air reports. Especially over the vast ocean areas of the Southern Hemisphere, about the only information available is the weather satellite depiction of polar storms and associated frontal systems, and of various tropical weather types. Even where many reports exist, the satellite views of the cloud and cloud systems reveal details which are not otherwise discernible.

Besides cloud imagery, NOAA polar orbiting satellites also obtain, by means of the vertical temperature profile radiometer (VTPR), profiles of temperature and moisture between the spacecraft and the ground. These VTPR soundings along with radiosonde and aircraft data are utilized in the computer models mentioned earlier which provide guidance regarding the movement and development of pressure systems.

In addition to the twice daily global satellite data available from NOAA polar orbiting spacecraft, NOAA GOES geostationary satellites provide 24 hour infrared and daytime visible coverage of North and South America and the adjacent ocean areas. Both GOES visible and infrared imagery are available as still pictures usually at 30 minute intervals and time lapse movie loops. In special situations such as tornado and hurricane conditions, the picture interval is reduced to 15 minutes. Cloud depiction from above gives a much better idea of where the significant weather is occurring. Movie loops enable the meteorologist to examine lower and upper level motions as revealed in the movement of clouds and cloud systems.

As important as computer and meteorological satellite products are in supporting remote sensing programs, you cannot eliminate the weatherman from the program when clouds and weather are a problem. The man-machine combination recognizes the fact that weather forecasting still has a high degree of "art" left in it. Generally, when the meteorologist is an active participant in specific programs, the chances of success are greatly improved. What follows describes the nature of SMG's involvement in past, current, and future remote sensing programs.

3. WEATHER SUPPORT FOR REMOTE SENSING PROGRAMS

The role of the meteorologist with regard to weather support for remote sensing programs varies greatly. It may involve premission planning, the RDTE phase, mission operations or postmission analysis. Mainly our work is operational support. In the Apollo Era of the U.S. Manned Space Program, SMG was involved in some aspect of all the different phases. Our participation in the Space Shuttle Program, as it unfolds, very likely will be similar to our role in Apollo. I would like to describe the nature of SMG's participation in several earth-sensing programs (manned and unmanned) to show how weather information can be used to accomplish specific program objectives.

3.1 U.S. Manned Space Programs

3.1.1 The Apollo Era - Mercury, Gemini, Apollo, Skylab, and Apollo/Soyuz

On July 1, 1960 the antecedent unit of what is now SMG was formed to provide weather support to NASA's Project Mercury. In the early Mercury days there was only partial global weather satellite coverage from TIROS-1, the first U.S. weather satellite launched on April 1, 1960. Computer barotropic atmospheric forecast models reached precariously out to 72 hours. In the Mercury program photography was mostly on a target-of-opportunity basis, although some forecasts were made for specific downward-viewing experiments. These forecasts were based upon climatology and on whatever weather satellite and conventional observations were available in the vicinity of the targets.

On the Gemini flights there was a number of experiments which required the photography of selected earth or cloud features or which required that the astronauts see particular features. The main aim of the Gemini series was the development of manned spaceflight technology. Therefore, there was only limited time for the scientific experiments, and only a limited supply of fuel available for reorienting the spacecraft to get the proper viewing attitude. Sometimes forecasting was important in scheduling the activities of the crew. Throughout most of the Gemini

series the Spaceflight Meteorology Group (SMG) prepared one map each day showing the continental areas where less than three-tenths cloud cover was expected for the daylight passes of the spacecraft.

Color and sometimes infrared photographs of earth features and cloud systems were a significant product of the Gemini scientific program. However, the great majority of the views taken did not require specific forecasts. They were taken as the opportunities arose as part of the general documentation of the flights or in response to prior requests by the experimenters; but some were the result of specific forecasts that the desired features could be seen on particular passes.

In addition to the photographic efforts, there were other experiments which depended on forecasting. For example, on Gemini 5 and again on Gemini 7, there was an investigation of the visual acuity of the crew. One part of this investigation involved the sighting of an array of large white rectangles placed on uniform terrain near Laredo, Texas. The crew had to judge the orientation of the rectangles -- which varied from 152 to 610 feet in length -- to indicate just how small a feature they could see. At one point in the Gemini 7 mission the prediction called for clouds to move over the ground site in about 48 hours and to preclude the conduct of the test at the times at which it had originally been scheduled. Because of that forecast of unfavorable weather, the visual acuity experiment was re-scheduled a day earlier than planned and was conducted successfully. It should be noted that the location of a relatively small target, such as the array of white rectangles in the visual acuity experiment, is difficult to spot in the brief time that it is within the astronauts viewing range. With even a few clouds in the area the difficulty is increased.

In the two manned Apollo earth-orbiting flights, Apollo 7 in October 1968 and Apollo 9 in March 1969, there were quite a few areas scheduled for photography. In the Apollo 9 mission with its greater emphasis on scientific benefits of spaceflights there was a particularly active program of forecasting for a great many potential targets on earth. As in the Gemini program, daily forecast maps were prepared which showed the areas where less than three-tenths of cloudiness was expected.

One of the many aims of the Apollo 9 mission was to get pictures of that year's extensive snowcover in the remote higher elevations of northern Arizona for the Office of Hydrology of the National Weather Service. After many days of cloud cover in that area the forecast for March 12 called for sufficiently clear skies. Accordingly, the crew was prepared and the spacecraft was oriented for photography to the north as it passed near that area. Several excellent pictures of the snowcover were obtained.

The Skylab missions, which required SMG to make sky cover forecasts as part of its overall weather support, involved extensive earth-oriented sensing experimentation. Unlike the Gemini and Apollo missions, where daily forecast maps showing continental areas where less than three-tenths cloud cover was expected for all daylight passes, forecasts for Skylab dealt with up to 4 or 5 candidate passes (each involving a number of experiments) selected five days in advance. Outside the U.S. initial selection was largely on a climatological basis. For the U.S. preliminary selection was made based on 5-day forecasts. Final selection of 1 to 2 passes for recording remote sensed data was made from a 2-day forecast covering all the candidate passes initially chosen three days earlier. The 1 to 2 passes selected to be recorded were the ones having the highest expectancy of favorable weather conditions in relation to the number of experiments along each particular pass. Time-lines of crew activities were developed from 1-day forecasts which took into account changes in weather during the preceding 24 hours affecting the designated tracks. The final go/no-go decision to record along the time-line was made about three hours before the time of overflight and was based upon the latest satellite and other available data.

Granted, such a selection process is rather involved. However, some 90 percent of Skylab's remote sensing program objectives were accomplished during the three Skylab missions. This was a much higher success factor than had been expected on the basis of premission assessment, and in part reflects favorably on the quality of weather support rendered. Skylab experiments were not confined to continental areas but included the ocean areas as well. In addition to forecasting cloud cover (clear, partly cloudy and cloudy) along the tracks, forecasts of frontal positions, storm centers, high pressure areas and wind and sea conditions were also indicated.

One sensor package aboard Skylab was the Honeywell S-192 multispectral scanner. Experimenters and applications mission planners wanted to compare the 13-channel skylab scanner with the four-

channel Landsat system to determine if the more advanced S-192 could achieve results not already obtained by the existing Landsat system or by other, cheaper ground or aircraft sensors. Unfortunately, random noise in Bands 1-5, those in the visible spectrum that were most directly comparable to Landsat bands, precluded such an evaluation. After more than a year's effort some of the noise was removed. This data along with that from the best channels (bands 7, 9 and 11 in the near-and mid-infrared part of the spectrum) provide a broadened collection of useful information for the Skylab experimentors and for future research. Channel 11 is of special interest to agriculture researchers. It has the potential for distinguishing between types of vegetation in imagery, possibly because of the way water is subdivided in plant cells. This band is being considered for use in a thematic mapper on Landsat-D which is another reason for interest in it. Resolution is higher in the S-192 system than in present Landsat imagery.

Skylab instrumentation also included a radar altimeter, which was the forerunner of the instrument flown on the Geodynamics Experimental Ocean Satellite (GEOS-3) Project to be discussed later. The Skylab experiment among other things was to demonstrate the use of radar altimeters to detect and measure oceanographic features such as surface roughness and wave heights. During the Skylab mission, SMG made forecasts of wind and sea conditions along a number of passes over both the Atlantic and Pacific oceans. After the mission careful analyses of surface information for selected portions of some 20 passes were made to provide the best estimate of winds, wind waves, swells and weather conditions for comparison with sea conditions measured by the radar altimeter.

Weather support for the earth-viewing experiments during the joint United States-Russian Apollo-Soyuz Test Project was similar to that for the Skylab missions.

3.1.2 Space Shuttle Era

The role of the SMG meteorologist becomes more operational as the Shuttle Program progresses phase by phase toward the operational Shuttle flights of the 1980s. So far our involvement has been primarily with such matters as meeting overall weather support requirements; special studies involving the effects of certain meteorological conditions on Shuttle landing and rollout; Shuttle approach and landing test simulations; weather aspects in the selection of foreign and domestic contingency landing airfields. SMG also supports the shuttle Astronaut training aircraft operations out to Ellington AFB (Houston, Texas) which began last year.

Recently the "captive inert" (orbiter unmanned) phase of the space shuttle orbiter approach and landing test (ALT) program was completed. This phase, consisting of five flights evaluated the flight envelope of the carrier aircraft/orbiter combination. In late May the "captive active" flights will begin with two astronauts aboard the piggyback shuttle orbiter operating its systems. Up to six flights may be involved. Between July and January 1978, eight free flights are scheduled in which the orbiter will be released from the carrier aircraft as the final phase of the ALT Programs.

With each passing phase of the flight testing programs, the consultant/advisory role of the SMG meteorologist to the NASA Johnson Flight Directorate personnel becomes increasingly more active. In 1979 six orbital flight tests are scheduled and operational shuttle missions will start with the Spacelab-1 mission in mid-1980. With the orbital missions the scope of the meteorologist's responsibility shifts from that of a local area to one involving essentially global operations.

The timetable for reaching specific shuttle development goals noted above makes one realize that shuttle operations are just around the corner. Earth-viewing activities are scheduled for two of the six orbital test flights in 1979. Spacelab-1 in 1980, a joint NASA and European Space Agency (ESA) undertaking, will be a one-week long mission keyed toward atmospheric and solar/terrestrial research, but also will involve significant space processing and life sciences projects. Seventeen NASA Sponsored and 61 ESA research proposals have been selected for the Spacelab-1 mission. NASA's research proposals involve 86 investigators and ESA's 61 proposals involve some 136 scientist. Undoubtedly, a number of the earth-oriented experiments will be affected by clouds thus requiring weather forecasting. Most likely, SMG weather support for earth-sensing Spacelab-1 experiments will be similar to that of the Skylab missions. When the Shuttle program reaches full development in the mid-1980s, up to 40 missions a year are anticipated.

3.2 Earth Observation Programs

3.2.1 Aircraft Programs

Since 1970, SMG meteorologists have provided weather support for earth sensing aircraft experiments conducted by the NASA Johnson Manned Spacecraft Center. In the early 1970s the NASA Earth Observations Aircraft Program (EOAP) was very active, partly as background for experiments scheduled on future space programs. A major effort of EOAP was the 1971 corn blight watch. The purpose of that experiment was to obtain repetitive color photographs in the near-infrared visible spectrum along more than 40 selected flight lines covering the belt of states from Ohio westward to Kansas and Nebraska. The objective was to obtain cloud free photographs of all flight lines every 2 weeks during the period June 15 to October 1. These photographs were analyzed to determine the degree of infection from the Southern Corn Leaf Blight and to monitor the development and spread of the disease. Almost daily forecasts of the cloud cover were required to schedule high-altitude aircraft flights over the target lines. Most flights were made by an Air Force RB-57F flying at an altitude of about 60,000 feet. Due to sun angle requirements for optimum lighting these lines could be photographed only during the hours 0900-1500 CDT.

To support the corn blight survey flights, SMG meteorologists were deployed to support aircraft operations first out of Scott AFB in Illinois and later out of Forbes AFB in Kansas. The meteorologist working with the on-site mission manager and aircraft commander were for the most part able to capitalize on the brief periods of generally clear weather before daytime cloudiness developed and following occasional weak frontal passages. In general there were few of the 2 week periods where any significant segments of the required flight lines were missed due to weather. Direct radio communications with the flight crew were very important to the high degree of success achieved. Such direct contact with the aircraft provided the flexibility to confirm or modify preflight instructions regarding developing weather conditions. The type of remote sensing technology demonstrated in the corn blight and other EOAP experiments is now being used in the Earth Resources Technology Satellite (ERTS - now Landsat) Program.

Again in November 1974, a SMG meteorologist was deployed with the flight crew of a NASA C130 aircraft to Copenhagen, Denmark. The purpose of the mission was to conduct flights out over the North Sea to calibrate radiometer-scatterometer (RADSCAT) and dual-frequency scatterometer (DFS) equipment. The RADSCAT equipment was flown later on the GEOS-3 satellite as part of the NASA Earth and Ocean Physics Applications Program (EOPAP). The North Sea flights were looking for high-wind, rough-sea conditions in various ranges to augment earlier calibration data. Fortunately, the weather cooperated and three missions were flown, one of which was a very good mission encountering the higher wind speeds desired ranging to more than 50 knots with accompanying seas. Improved RADSCAT and DFS equipment will be flown along with other instrumentation on SEASAT-A in May 1978 which is also part of EOPAP. The GEOS-3 and SEASAT-A Projects will be discussed later in regard to SMG's involvement. From the foregoing it is readily seen how interrelated are the aircraft and satellite programs, both manned and unmanned.

As mentioned earlier, the aircraft program was very active during the first part of the 1970s. The NASA Johnson SMG office, as part of its overall center support, provided forecasts for EOAP flights covering the central and western part of the U.S. When the aircraft staged out of Langley Virginia or McGuire AFB in New Jersey, weather support was furnished by SMG meteorologist at Washington, D.C.. A typical mission usually involved 8 to 10 experiment sites scattered over a several state area. Next day scheduling was based on a 24-hour forecast, selecting sites where most favorable weather conditions were expected and the aircraft readied accordingly. On the morning of each flight prior to alerting the flight crew, the final go/no-go decision would be made by the mission manager after being briefed on the latest weather conditions by the SMG meteorologist. The main benefit of this type of weather support arrangement is that having a meteorologist specifically responsible for mission support increases the opportunity to capitalize on favorable weather conditions. Also, it permits more orderly use of flight crew ground time.

Today, the NASA Johnson aircraft program, now known as the Airborne Instrumentation Research Program (AIRP), is not as active as in the early 1970s. AIRP aircraft remote sensors include cameras, microwave radiometers, multi-spectral scanners, precision radiometer thermometer, laser profiler, and scatterometers. Various combinations of these sensors are used to obtain data at locations throughout the U.S. for use by some 100 scientific investigators. Like EOAP,

AIRP is part of NASA's Earth Observation Program developing remote sensors and remote sensing technology.

3.2.2 Landsat - Earth Resources Technology Satellite Program

Remote sensors aboard the Landsat spacecraft put the whole earth under a microscope. Circling the globe every 103 minutes in a near polar 920-km (570-mi.) orbit, the spacecraft's remote sensors view a 185-km (115-mi.) wide strip along a ground track running nearly north-to-south at an angle to the equator of 99 degrees. In this type of orbit, surface coverage of the Earth progresses westward, with a slight overlap, such that complete global coverage is obtained once every 18 days. Landsat-1 (launched July 23, 1972) and Landsat-2 (launched January 19, 1975) are in sunsynchronous orbits with equator crossings at the same time (9:30 a.m. local time) every orbit. Both spacecraft carry the return beam vidicon camera subsystem and the multi-spectral scanner subsystem.

Synoptic, repetitive coverage of the Earth's surface under consistent observation conditions is required for maximum utility of the multispectral imagery collected. Later this year with the launch of Landsat-C, nighttime sensing will be possible because of the addition of a fifth channel to the multispectral scanner in the infrared spectral band.

Data from the remote sensors of the Landsat spacecraft are used by more than 100 research teams in Federal, State and Foreign Governments, international organizations, universities and private companies involving the scientific disciplines relating to the Earth, its resources and their use. More than 40 states and more than 40 foreign countries participate in the Landsat follow-on Investigative Program designed to show the practical benefits in resource management utilizing remote sensing from space. Applications of Landsat data are being made in such fields as agriculture, forestry, range resources, marine resources, oceanography, mineral and land resources, mapping and charting, water resources, environment, and land use.

But, what about clouds? Cloud cover interferes with obtaining remote sensed imagery of the Earth's surface. Where clouds exist, reduction in coverage is unavoidable, but it would be wasteful to use up the limited lifetime of the spacecraft recorder on useless imagery. Hence, NASA's operational plans for Landsat included cloud-cover forecasting. To meet this need the SMG Washington Section provides operational global cloud cover forecasts for Landsat support. As a result of SMG's extensive experiences in meeting the worldwide weather requirements of the Manned Space Program, SMG was the logical choice to provide cloud cover support for the Earth Resources Technology Satellite Program.

Each day a forecast of cloud cover is prepared for all the land areas and some adjacent ocean areas beneath the track for each of the next day's 14 passes. For the first pass, the forecast is about a 24-hour prediction; and for the last pass about 48-hours. The cloud forecasts are made in three categories: "clear" (0 to 30 percent sky cover), "partly cloudy" (31 to 69 percent), and "cloudy" (70 to 100 percent).

Daily forecasting of cloud cover for all parts of the world a day or two in advance is certainly not an easy task. The SMG Washington Section making these forecasts is colocated with the National Meteorological Center (NMC) and pertinent parts of the National Environmental Satellite Service (NESS). It has ready access to the global data and products of these two NOAA components. In making the cloud cover forecasts, the forecasters have available all NMC data and guidance products to use in estimating the future location of pressure systems. A special computer program adapts the NMC guidance information to the map base and orbit times to meet the needs of the Landsat Program. The clouds associated with the various weather systems (and clouds not identified with features on analyses) are most reliably depicted in weather satellite photographs. Movie loops made from GOES satellite imagery are also helpful to the forecaster. The basic importance of computer and weather satellite products to the meteorologist in support of today's remote sensing programs has already been discussed. One might almost say, the meteorologist would be lost without them. Certainly the quality of weather support would be adversely affected if they were not available.

How good are the Landsat cloud cover forecasts? A recent verification of 69 days (966 orbits) of Landsat forecasts shows that when clear skies were forecast, they were observed 60 to 70 percent of the time for various parts of the world. Clear or partly cloudy skies were observed about 85 percent of the time when clear conditions were forecast; thus indicating

some useful information is possibly obtained that much of the time.

On a few occasions, special requests for a nighttime forecast are received. One particular case was to satisfy the requirement to take Landsat-2 photographs of "gas flaring" in the vicinity of 32°N 06°E in Algeria for January of last year. Photographs taken captured the gas flaring from petroleum production in that area. The most recent request for a nighttime forecast was along the Santa Barbara channel area northward to San Francisco, California. From the weather standpoint the target area was beautifully clear. Such requests are unusual in that nighttime photographs are being attempted using daytime sensors.

Besides Landsat-C to be launched later this year which will have the added nighttime sensing capability, NASA plans call for the launch of the Landsat-D spacecraft in 1981. It is not certain at this time whether the multispectral (S-Band) scanner flown on the first three Landsat spacecraft will be flown on Landsat-D in addition to the planned high-resolution (X-Band) mapper. NASA was unable to add the multispectral scanner to Landsat-D with its own funds. It remains to be seen if users are willing to fund for inclusion of the scanner. Landsat-D will be designed to be compatible with the Space Shuttle System for retrieval by the Shuttle orbiter.

3.3 Ocean Satellite Programs

3.3.1 Geodynamics Experimental Ocean Satellite (GEOS-3) Project

The GEOS-3 satellite was launched the first part of April 1975. The primary objective of the GEOS-3 Project was to demonstrate the feasibility of utilizing an on-board radar altimeter to measure the time-varying behavior of the ocean's surface and the departure of the sea surface from the geoid, as well as to investigate altimeter instrumentation technology. The altimeter measured variations in the shape of the leading edge of the reflected radar pulse from the ocean's surface. To obtain engineering data on altimeter performance, it was necessary to measure and evaluate parameters such as sea surface roughness and spacecraft libration. To achieve this the altimeter had to be calibrated over an ocean area; the area just off the East Coast of the U.S. was used. Altimeter accuracy was determined by comparing the altitude measured by the altimeter to the spacecraft altitude determined by independent tracking systems located at Wallops Island, Virginia; Cape Kennedy, Florida; Grand Turk; and Bermuda. Precision and resolution were determined by comparing sea surface profiles resulting from altimeter measurements with profiles determined by independent methods.

SMG's primary involvement with GEOS-3 dealt with providing independently determined sea surface profiles for comparison with those determined by the spacecraft altimeter. For the better part of a year, SMG provided the NASA Wallops GEOS-3 Project Manager ground-truth information based upon standard hindcasting procedures using surface weather charts for the two or three passes each day over the calibration area off the East Coast. Separate determinations were made of the wind wave and swell components which together are a measure of the sea surface roughness. Ground truth for some portions of passes outside the calibration area were also estimated. Hindcasting methods represent average conditions along the track and not the instantaneous conditions as measured by the altimeter. Hence, only comparisons of average conditions were possible. Naturally, there were times where significant differences were noted. Generally, there was reasonable agreement when significant changes in sea surface roughness took place even though altimeter recorded profiles usually indicated higher peak values than the hindcast method. The GEOS-3 altimeter is more sensitive to the higher wave heights than the lower ones. It is with the higher end of the wave height spectrum that the observer has difficulty in estimating height values and also where hindcasting methods underestimate the higher values.

For the month of February 1976, a major effort was made to evaluate the performance of the altimeter. Sea surface conditions were recorded for all passes over the North Atlantic during the month. The number of passes varied from seven to nine per day. For each pass, SMG provided ground-truth which consisted of the heights and periods of wind waves (the significant wave height - the height of the highest 1/3 of the wind waves) and swells as well as the direction and speed of the wind at one minute intervals along the ground track. General weather conditions were also indicated along each track. NASA Wallops personnel have made comparisons of the GEOS-3 sea surface profiles with those calculated by SMG. Comparisons with aircraft, data buoy, and ocean weather ship information have also been made. Undoubtedly, the GEOS-3 and aircraft results best represent the instantaneous variations in the roughness of the sea surface. In magnitude, the altimeter results probably best represent a truer picture of the higher wave values. In

spite of shortcomings in the various methods of obtaining comparative data, there was good agreement much of the time. But there were also cases of substantial differences which left in question as to which data source was the better estimate. Nevertheless, GEOS-3 without question demonstrated the feasibility of measuring the sea surface roughness from space.

SMG is presently involved in the NASA SEASAT Ocean Dynamics Program in support of NOAA's SEASAT-A Research and Applications Plan. The SEASAT-A system is unique because its instrument complement is fully dedicated to oceanic requirements. Sensors on SEASAT-A, to be launched in May 1978, will provide near all-weather monitoring of the ocean surface by utilizing the microwave region with each type of microwave sensor represented. The SEASAT-A satellite will carry four microwave sensors consisting of a radar altimeter, scatterometer, synthetic aperture radar and microwave radiometer, plus a fifth sensor, a visible and infrared scanner designed primarily for feature identification. With the exception of the synthetic aperture radar, there is a strong space heritage for each of the instruments. Hence, each instrument has a high probability of meeting its mission objective. The microwave instruments on the spacecraft will provide data on surface wind fields, waves, storm surges, sea surface temperatures, currents, sea and lake ice, geoid, tides and ocean pressure gradients unobscured by cloud or lighting conditions.

For now, SMG is working with other National Weather Service (NWS) personnel continuing to examine the accuracy of GEOS-3 sea state data and looking into ways of possibly incorporating GEOS-3 data in the current NWS computer sea state program experimentally. Such development work using GEOS-3 data, if successful, paves the way for more expeditious use of SEASAT-A data operationally either by incorporation in the computer sea state program or by modification of the computer output products.

3.4 Deep Space Programs

3.4.1 Jet Propulsion Laboratory's Mariner-Jupiter-Saturn '77 Project (MJS '77)

For almost two years SMG has been working with the Jet Propulsion Laboratory (JPL) who has developed a Weather Effects Prediction Model to forecast the degree of weather induced X-band communication link degradation with regard to operation of NASA's Deep Space Network (DSN). The model will predict atmospheric attenuation and noise temperature increase under differing weather conditions affecting the X-band communications link between the DSN stations (Goldstone, California, near Madrid, Spain and near Canberra, Australia) and unmanned space probes, such as, the MJS '77 spacecraft to be launched later this year.

Why is it necessary to predict the weather effects on X-band communications in the operation of the DSN? Clouds and rain adversely affect the quality of the data received. The effect is proportional to the rain rate and cloud liquid water content which is a function of the water particle size and distribution. Under adverse weather conditions in order to maintain consistent high quality picture receipt, it is necessary to slow the data rate, thus reducing the quantity of data received. Under clear sky conditions, including Cirrus (ice crystal) clouds, consistent high quality data receipt can be obtained at high data rates. The data rate may be varied from about 115 kilobits/sec to about 7 kilobits/sec. Hence, advance knowledge of adverse weather effects is desirable in making decisions concerning operation of the DSN.

Up until now, the weather effects model has been tested only for the Goldstone location using actual forecast conditions. This is where SMG fits into the picture. We provide daily forecasts for the 850, 700, and 500 mb. levels, cloud amounts, cloud heights, cloud types, precipitation rate and thickness of the precipitating layer above the ground are also forecast. These forecast values together with judiciously chosen values representing the liquid water content of the forecast cloud types are run by JPL through the computer weather effects model to obtain predicted zenith angle atmospheric attenuation and increased system noise temperatures. The forecast results are compared with measured on-site microwave and weather data to update the weather effects model as necessary.

Weather conditions fall into three general categories: Clear, clouds (partly cloudy to cloudy) without rain, and clouds with rain. For the clear category, weather model forecast values indicate noise temperature increases of less than 1° Kelvin which are in good agreement with measured values. For the partly cloudy to cloudy, no rain situations, increases are small usually 1 to 2° Kelvin at zenith indicating that effects of clouds without rain are small. For the rain category, the two dry winters in southern California have not provided much opportunity to obtain forecast and measured

results to compare. However, hurricane Kathleen which crossed the extreme northern part of Baja California on the 10th of September last year, produced considerable rain in southern California and provided a good opportunity to compare the results of the SMG/JPL forecast values with measurements taken at the Goldstone site.

Hurricane Kathleen formed on the 6th and 7th of September about 600 miles south of the southern tip of Baja California. On the morning of the 9th, Kathleen was moving slowly NNW'ly and was located about 225 miles SW of the tip of Baja. Later on the 9th, Kathleen began to accelerate and tend more N'ly in direction. Acceleration continued on the 10th with Kathleen crossing the Baja California coastline about midday 100 miles south of San Diego. The remains of Kathleen spent herself over southern California and the Southwest.

Now, let us consider the 1, 2, and 5-day SMG forecasts verifying at 2000 G.C.T. for the Goldstone area. Only the 1-day forecast called for rain affecting the antenna site. When the 5-day forecast was made, the cloudiness in the area where Kathleen formed did not indicate any evidence of an organized circulation. GOES satellites provide 24-hour surveillance of the whole area. Disturbances which form south of Baja generally move W or NW'ly and dissipate when reaching the colder waters. Some do recurve striking Baja, but few cross the coast far enough north to affect the southern California area. The SMG 2-day forecast called for clouds only for the Goldstone area. At the time of the forecast, Kathleen was expected to move inland over Lower California further south than she did and produce clouds but no rain at the antenna site. By the time of the 1-day forecast, it was evident that Kathleen would definitely affect the antenna site; accordingly, the SMG forecast called for a thick layer of clouds and a rain rate of 25 mm/hr. (1 in./hr.).

The 1-day forecast (clouds + 25 mm/hr. rain) calculated a noise temperature increase of 58.51°K. The 10 mm/hr. rain rate observed calculated an increase of 30.18°K. The measured values over a four hour period centered on the forecast time, local noon P.S.T., show variations from 15°K to 60°K. For three hours of this period, the measured values fluctuated within 10° either side of the 50°K noise temperature line. Granted there are a number of uncertainties regarding the accuracy of weather forecasts, their verification and the nonhomogeneity of weather conditions surrounding the antenna site. Nevertheless, the differences in the forecast and observed values in this case seem reasonable and suggest that at least model results are in the right ballpark.

Recently, SMG began making weather forecasts for the antenna site near Madrid, Spain. Forecasting for the site near Canberra, Australia will probably begin later this year when background work now in progress is completed.

3.5 Miscellaneous Programs

3.5.1 NASA Langley's Tropospheric Research Technology Operating Plan (TRTOP)

From time to time, SMG has provided meteorological assistance for Langley programs. One such project involved operational forecasting for RB-57 aircraft clear air turbulence investigations over the middle Atlantic coastal states. The most recent project in support of Langley's TRTOP involved the selection of worldwide ground-truth monitoring sites in support of tropospheric pollution monitoring satellite systems to be flown late in the 1970s. Most of their sensors (visible and infrared) will have their observations degraded by the presence of clouds.

Satellite derived relative cloud cover climatology was used to make the initial selection of over 100 worldwide ground-truth monitoring sites. Of this number, annual, monthly and 3-hourly information for 0-1/8, 0-2/8, 3-5/8, and 6-8/8 total sky cover were derived for a network of 60 stations using available standard weather summaries. The cloud cover data was for use in computer simulation studies.

4. SUMMARY

The purpose of this paper was two-fold: First, to be informative regarding meteorological support rendered a number of remote sensing programs, and second, to be persuasive regarding the role of the meteorologist when an active participant in specific programs. Hopefully, this has been accomplished in an interesting manner.

SATELLITE-TO-GROUND TRANSMISSIONS FOR AMATEURS AND PROFESSIONALS

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SUMMARY

High school and college students, amateur radio enthusiasts, commercial organizations and government agencies in more than 120 countries have built or bought relatively inexpensive electronics equipment to receive images transmitted directly from earth satellites. These Automatic Picture Transmission (APT) and Weather Facsimile (WEFAX) ground terminals open new horizons for the scientifically-minded "amateur" interested in studying clouds, snow and ice cover, ocean currents, and other terrestrial features, while at the same time providing a challenge for those who like to test their electronics expertise. Globally, government agencies use APT and WEFAX stations in conjunction with conventional observation sources to support air and sea transportation, fishing and wildlife management, locust control, agricultural needs, development of natural resources, and a wide variety of other weather-related activities.

USE OF AN INERTIAL NAVIGATION SYSTEM FOR ACCURATE TRACK RECOVERY
AND COASTAL OCEANOGRAPHIC MEASUREMENTS

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ABSTRACT

A data acquisition system using a Litton LTN-51 inertial navigation unit (INU) has been tested and used for aircraft track recovery and for location and tracking from the air of targets at sea. The characteristic position drift of the INU is compensated for by sighting landmarks of accurately known position at discrete time intervals using a visual sighting system in the transparent nose of the Beechcraft 18 aircraft used. The angular direction data from the sight in conjunction with the aircraft's attitude and barometric altitude, enables the aircraft's 'true' position to be determined. A modified cubic spline interpolation routine was then used to approximate the continuous drift of the INU with time. For an aircraft altitude of about 300 m, theoretical and experimental tests indicate that calculated aircraft and/or target positions obtained from the interpolated INU drift curve will be accurate to within 10 m for landmarks spaced approximately every 15 minutes in time.

For applications in coastal oceanography, such as surface current mapping by tracking artificial targets, the system allows a broad area to be covered without use of high altitude photography and its attendant needs for large targets and clear weather. Data is collected in digital form enabling the data to be easily processed and the results plotted directly.

1. INTRODUCTION

For many airborne remote sensing applications, an accurate record of aircraft position is essential. Over land, a simple and widely used technique for obtaining this information is to compare photographs taken during the flight with accurate control maps of the flight path area. This technique is awkward, time consuming and cannot in general be used over water unless the area to be studied is sufficiently close to the shore or to known navigation markers. Several radar based or low frequency radio systems are also available, but these are either not very precise (errors of ≈ 100 m) or require the setting up of auxiliary ground stations.

Inertial navigation produces an extremely precise measurement of aircraft position and attitude, but has associated with it a reasonably large drift error in position which, if uncorrected, would prove to be unacceptable for many remote sensing applications. This characteristic drift can be compensated for in hybrid systems in which data from a less precise but drift free sensor

are also used^{1,2}. The system described here uses a visual sight to make periodic fixes on landmarks of known position to correct the drift error, resulting in track recovery accurate to ± 10 meters. This system has been investigated for use in flight path recovery for airborne survey operations³. A particular advantage of using a sighting system for establishing aircraft fixes is that the same apparatus may also be used to determine the positions of additional sighted targets such as floating drogues or linear surface features.

This paper describes the system configuration and the computations by which the INS drift errors are determined from the sighting data. Results of tests of system accuracy are presented, and several oceanographic applications in mapping sea surface features and currents are discussed in detail.

2. INERTIAL SYSTEM AND TARGET SIGHTING APPARATUS

Details of the inertial/sighting system have been described previously,³ therefore, only a brief description is presented here. The inertial navigation unit used was a Litton LTN-51 with standard software designed for airline navigation. The unit operates by sensing aircraft accelerations along three mutually perpendicular axes on a gyrostabilized level platform. The platform is maintained level by applying torquing signals to the gyro axes derived from the movement of the aircraft over the earth's surface. The computations necessary to provide the correct torquing signals are performed by the unit's own internal digital computer. These calculations assume a spheroidal earth with a flattening ratio of 1:297 and a constant aircraft altitude of about 10,000 m. This computer also calculates standard output data from the INU including aircraft position and velocity data as well as navigation information useful in commercial airline operations. In addition, high accuracy aircraft attitude (pitch, roll and azimuth) is available directly from angle resolvers attached to the level platform.

The standard output data is of limited value, however, because of two factors; 1) the computer cycle time gives relatively infrequent updating of this data and 2) intentional internal rounding reduces its accuracy. In order to circumvent these problems, a specialized data acquisition system, MIDAS (Marine Inertial Data Acquisition System), was developed. MIDAS was designed and constructed by MacDonald Dettwiler and Associates Ltd. of Vancouver and is an outgrowth of the system they designed and constructed for the Canada Centre for Remote Sensing in Ottawa⁴. MIDAS allows direct readout of the INU's internal computer memory, so as to give rapid access to the high precision navigation data. This data is output at a rate of 20 samples/sec and is used to calculate high precision aircraft position, velocity and direction. MIDAS allows, in addition, data input from eight analog channels (100 samples/sec) as well as other user supplied sensors. This data together with the observation time is subsequently output to either video or industry compatible magnetic tape. In the latter case, the user has the option of choosing between several recording modes depending on the frequency at which data recording is desired.

The target sighting apparatus consists of a zero parallax shotgun sight on an alt/azimuth mount located in the transparent nose of the aircraft, a Beechcraft 18. A precision potentiometer on each axis of the mount enables the sighting angles relative to the aircraft to be monitored. This is accomplished by placing a regulated dc voltage across each potentiometer resulting in an output dc voltage proportional to the sighting angles. The output voltages from these potentiometers are input to two of the analog channels. Operation of the sight is controlled by an observer lying in the nose of the aircraft. During the flight, the observer aims the sight at either landmarks of known position or visible surface objects or features to be positioned. When the sight and the target are aligned, the operator pushes a 'record' button which places a positive voltage on a third analog channel, identifying the target for later processing. The magnitude of this voltage is controlled by the operator

and allows for up to 100 different targets to be identified.

As was mentioned previously, MIDAS allows several modes of recording data on magnetic tape. Normally, INS data is output at the maximum rate of 20 samples/sec (100 samples/sec for the analog channels). For most of the flights, however, where no additional sensors were present, INS and sight data needed only to be recorded at discrete time (i.e., when a target was being sighted) and in short bursts lasting about one second. In order to reduce the amount of output data in these flights, MIDAS was modified to allow for a much slower background recording rate of only one sample/sec. In this mode, continuous recording is re-enabled while the 'record' button is pressed. The one sample/sec background recording rate was found to be more than adequate for post flight track recovery.

Calibration of the sight in the laboratory resulted in an estimated RMS error of 0.18° . Additional calibrations of the sight in the aircraft were also performed in order to establish the orientation of the sight mount with respect to the INU. It is estimated that the combined calibration error is less than 0.5° .

3. INTERPOLATION OF INERTIAL SYSTEM DRIFT

In order to maintain the gyro-stabilized platform level as the aircraft moves over the earth's surface, the INU's internal computer provides gyro torquing voltages calculated from the measured horizontal movement of the aircraft. The LTN-51 inertial unit used in this study is 'Schuler tuned', that is, the torquing voltages are made proportional to the aircraft's angular velocity relative to the center of the earth. The inertial platform, therefore, behaves as a Schuler pendulum¹ and as such, if perturbed undergoes stable oscillation about the level position with a period T given by

$$T = 2\pi \left(\frac{R}{g} \right)^{\frac{1}{2}} \quad (1)$$

where R is the earth's radius and g is the acceleration of gravity. This oscillation, which has a period $T = 84.4$ minutes, results in an approximately sinusoidal drift in the calculated positions (latitude and longitude) returned by the INU. The fact that the INU drift is not perfectly sinusoidal arises from additional error mechanisms within the inertial system. The amplitude of the mean drift, in normal circumstances, is of the order of 2 km per hour.

Utilizing the target sighting apparatus, the magnitude of this drift may be determined at discrete times by sighting landmarks on the earth's surface of accurately known position. The angular direction data from the sight in conjunction with the aircraft's attitude and barometric altitude is used to establish the aircraft's 'true' position using the known position of the sighted landmark. It should be mentioned here, that the relatively large position drift of the INU results from only relatively small ($\sim 1'$ arc) angular errors in the gyro-stabilized level platform. Thus errors present in the attitude data will be negligible in comparison to the estimated errors in the sighting angles. The difference between this 'true' position and that returned by the INU determine the error due to inertial system drift (north and east) at the time the target was sighted. During flight, target sightings were generally restricted to observing angles less than 30° off nadir in order to reduce the effects of errors in sighting angles and in the aircraft's indicated barometric altitude. For the present experimental system, it is estimated that for an aircraft altitude of 300 m these errors will be of the order of ± 5 m.

An estimate of the INU drift for intermediate times is then obtained by fitting a modified cubic spline to the resulting discrete drift data. A cubic spline was chosen over more complicated fitting procedures (e.g., Kalman Filtering)^{2,6} on the grounds of simplicity and much reduced analysis time. It

should be noted, however, that a cubic spline interpolation will maintain a smoothly varying position and velocity drift and to this extent will tend to duplicate the actual drift behavior of the inertial system. In addition, a spline interpolation does not require continuous monitoring and/or recording of aircraft navigation and attitude data, a significant advantage for longer flights.

In order to estimate the possible errors involved in fitting a cubic spline to the discrete drift data, a theoretical study was carried out in which a modified cubic spline was fitted to a set of hypothetical drift measurements. The particular spline fitting routine used here differed from the classical spline fit in that the fitted curve was allowed to deviate from the data points by specifying an allowable maximum sum of squares error in the fitting routine. This procedure is more suited to the experimental conditions considered here where finite errors in individual position fixes are to be expected.

Postulating a sinusoidal velocity drift in the inertial system, the position and velocity drift, to first order, may be specified by the following equations;

$$v = A \cos(\omega t + \phi) + B \quad (2)$$

$$S = \frac{A}{\omega} \sin(\omega t + \phi) + Bt + C \quad (3)$$

where $\omega = \frac{2\pi}{T}$, $T = 84.4$ min and ϕ is the phase angle. Comparing Eq. 3 with actual drift data obtained from test flights of the system indicates that for time periods up to several hours after initial inertial system alignment, the position drift is predominately sinusoidal ($B \approx 0$) with A ranging between 1 and 2 m/sec. The value of C , although in general non-zero, is arbitrary for this study in that it has no effect on the fitting procedure.

The test procedure involved fitting a modified cubic spline to simulated drift curve data obtained from Eq. 3 for values of A between 1 and 5 m/s and fixed time intervals between data points of from 1 to 20 minutes. In order to allow for different starting phase angles, ϕ was varied, for each time interval, from 0 to 2π in steps of $\pi/10$. In addition, to further simulate actual experimental data, normally distributed random errors with a specified standard deviation σ were added to the individual data points. The maximum sum of squares error for the cubic spline routine was set so as to equate the RMS error in the data and the allowable RMS error in the spline fit. The RMS difference between the sinusoidal curves and the cubic spline was then computed for each case.

The results of these tests are shown in Figs. 1a and b. Here the effect on the RMS difference of varying σ with a fixed A and the effect of varying A with a fixed σ are plotted. The most striking feature in both plots is that for time intervals between data points ranging from 5 to 10 minutes (300-600 secs) the RMS difference, which represents the interpolation error in fitting the modified cubic spline to the sine curve, is essentially constant at a value equal to the assumed RMS error in the simulated data. Thus, for position fixes obtained every 5 to 10 minutes, the interpolation error in predicting the actual INU drift will be approximately determined by the accuracy to which the position fixes are obtained. For time intervals exceeding 10 minutes the interpolation error tends to increase fairly rapidly depending on the drift amplitude A . Conversely, for decreasing time intervals less than 5 minutes, the interpolation error approaches zero as errors in the many sightings tend to average out.

As was mentioned previously, a reasonable estimate for the RMS error in the positions fixes for the target sighting apparatus used here is ± 5 m.

Figure 1b, therefore, shows that for a typical value of $A = 1.5$ m/sec, the RMS interpolation error will be less than 10 m if position fixes are obtained at least every 15 minutes. For the aircraft used in this study, this represents a ground distance of about 75 km.

It should be mentioned, however, that these error estimates will hold only if the drift of the inertial system behaves 'smoothly' between position fixes. This has been found to be largely the case for test flights of the present system. Maneuver dependent error mechanisms in the INU such as azimuth drift will introduce however, small errors in the indicated positions which will be largely a function of distance travelled from the nearest position fix and as such will not follow the time dependent Schuler drift. Azimuth errors of up to 50" arc have been identified in the present system in several test flights resulting in cross-track errors of up to 2.5 m per km. It is therefore evident that not only the time spacing of position fixes is important, but also the location of the study area relative to the reference landmarks. Specifically, for example, if the study area lies approximately along a line between two landmarks, the resulting ground position errors due to errors in azimuth will be minimized. For the test flights discussed here, the landmarks were chosen with this criterion in mind. It should be mentioned also that one advantage in Kalman Filter analysis is that errors of this type would be modelled as part of the total system error response and are therefore taken into account.

4. FLIGHT TEST OF INERTIAL/SIGHTING SYSTEM

In order to determine the errors involved in using the inertial/sighting system for flight path recovery under actual in-flight conditions, several test flights were conducted both over land and over local coastal waters near Victoria. One such test flight was carried out along a relatively straight 30 km section of highway for which accurate 25,000 scale topographic maps were available. The flight path ran along the Patricia Bay Highway on Vancouver Island between Swartz Bay and the southern tip of the City of Victoria. The highway was flown in both directions (North/South) at an aircraft altitude of about 300 m. The purpose of the flight was to compare the calculated and measured positions of major road intersections at approximately 2 km intervals along the highway. Target positions and elevations above sea level were obtained from four separate topographic maps of the region. The target elevations were needed to compute the altitude of the plane over each sighted target. The actual position of each road intersection were obtained from the appropriate map of the area using a flat bed digitizer. Deviations between the known and calculated positions of each intersection are shown in Fig. 2. As is evident, the drift of the inertial system is relatively constant in latitude at about 560 m North, and in longitude varies from a minimum of 420 m to a maximum of 720 m East. A drift curve for the INS was calculated by fitting the modified cubic spline ($\sigma = 5$ m) to the data from two of the road intersections located near the northern and southern ends of the highway and reference landmarks at the beginning and end of the overall flight path. The particular road intersections were chosen in order to obtain an approximately equal time spacing (≈ 6 minutes) between the reference data. By interpolating along the cubic spline, the positions of the remaining road intersections were calculated and subsequently compared with their measured values. The resulting average errors in latitude and longitude were -5 ± 9 m and -7 ± 9 m respectively. These averages do not include data from the six most southerly intersections (see Fig. 2) because of a visible discontinuity across the boundary of the topographic map of that particular portion of the highway and the next adjoining map in the series. When averaged separately the data for these intersections showed an average error of 23 ± 6 m in latitude and -14 ± 7 m in longitude. Considering that a significant portion of the above errors can be attributed to map and digitizer inaccuracies which could be as large as 10 m, these standard deviations compare favorably with the theoretical study described previously. Finally, Fig. 3 shows a map of the aircraft flight path corrected for INS drift using the fitted cubic spline. For comparison, the uncorrected flight path returned by the inertial system is also shown.

5. OCEANOGRAPHIC APPLICATIONS

As was discussed previously, one of the advantages in using a target sighting system for establishing inertial system drift is that the same sighting system may also be used to determine the position of secondary targets and/or surface features on the earth. This has particular application in the area of coastal oceanographic remote sensing; specifically, the monitoring of surface water movement in a variety of situations. Generally, these types of measurements are conducted by monitoring the movement of fluorescent dyes and/or floating drogues. These are monitored either by aerial photography⁷ or, for the latter, by various electronic positioning systems^{8,9}. In the studies referenced above, typical accuracies for position determination ranged from 100 to 200 m. This accuracy is sufficient for studies of gross surface motion, or which are to be conducted over a relatively long time span (1-2 hrs between sightings). For studies where the movement is restricted to a short period of time or where monitoring time is limited, however, this type of accuracy would likely be insufficient. In addition to this, aerial photography, which is heavily relied upon in dye dispersal or river outflow studies for example, is severely limited in some areas due to extended periods of low cloud cover. Cloud cover is particularly restrictive when higher altitude photography is required to give a large enough field of view so as to encompass sufficient reference landmarks. It should be mentioned here that this restriction is more severe for the various environmental satellites because of the limited number of passes of the satellite over the area to be studied in any given time.

Most of these problems, however, are avoided in the present system, due to the increased position accuracy (≤ 10 m) and the ability to work at low altitudes even when large areas need be covered. An additional advantage in the present system is that the mapping data is stored in digital form thus bypassing the digitization phase which is often ultimately required in many of the more conventional monitoring techniques discussed above. This feature is particularly useful in producing scaled plots of the data which may be readily overlaid on available maps of the study area. The results of several test flights of the present system involving various oceanographic measurements are discussed below.

In the first test, a flight was organized in conjunction with ocean dumping experiments carried out by the Pacific Region of Ocean and Aquatic Sciences (OAS) in February 1976. The purpose of the experiments was to ascertain some of the ecological and chemical effects of dumping various material at sea. During each dump various monitoring techniques employing drogues, dyes, bottom samples, etc. were used to study the effective dispersal of the dump material as a function of time. The dump area is located off Point Grey near the City of Vancouver and is the largest dump site in Canada for ocean dumping disposal of waste material. The particular dump which was monitored occurred at 1335 hrs. on February 9 and consisted of coarse Fraser River dredge material. During the monitoring the aircraft was flown at an altitude of 300 m in a roughly circular path encompassing the nominal dump site and reference landmarks at Pt. Atkinson, Cowan Pt. and a marker light off Pt. Grey. The average time interval between landmarks for this circuit was about 2.5 minutes (150 secs). A map showing the calculated position of the sighted dump material and the landmarks is shown in Fig. 4. Here, an enlarged view of the dump material is shown in insert, with the numbers indicating the approximate time to the nearest minute into the dump.

A total of six passes were made over the dump material after dumping commenced. Because of uncertainty in knowing exactly when the dump was to occur (due to lack of communication between the aircraft and the dumping barge) it was necessary for the aircraft to maneuver over the dump area for a considerable length of time before the actual dump. This was not an ideal situation, unfortunately, for determining the INU drift because of the aircraft's accelerations during the maneuvers and because it was not possible during this time to sight a reference landmark. After dumping commenced, however, it was possible to sight the marker light off Pt. Grey between the fourth and fifth pass over the dump material which significantly reduced

interpolation errors in the drift curve. From the drift data, it is estimated that the absolute position error for the dump material during any pass should be less than 15 m. In addition to the sighting data, color photographs were taken of the dump material using a 70 mm Hasselblad camera mounted in the belly of the aircraft.

The results of the mapping test, as shown in Fig. 4 indicate that the visible portion of the dump material had a physical extent of about 600 m and, during the 8 minutes in which the material was monitored, underwent a roughly counter-clockwise rotation with a maximum displacement of about 90 m implying velocities of the order of 0.2 m/s. It should be mentioned, however, that the dump material became very difficult to see during the last two passes and thus some of the movement may well be due to operator sighting inaccuracies. Aside from the above movement, however, no bulk displacement of the dump material is evident. Examination of color photographs taken of the dump material during the first four passes indicates that the material was reasonably visible within one or two minutes after the dump. After this time the visibility decreased noticeably. Unfortunately, due to the limited field of view of the camera at this altitude, it was not possible to correlate the position of the dump material from the photographs with the MIDAS data.

In a second study, the development of a distinct river silt plume front was mapped at the mouth of the Fraser River south of Vancouver. Here again, a roughly circular path was flown, however, on this occasion at an altitude of 900 m. A higher altitude was used in order to provide for an increased field of view of the area to be studied. This did, however, result (as expected) in a slightly larger experimental error. Figure 5 shows a map of the calculated positions of the silt plume front and the reference landmark used overlaid on a chart of the area. Approximately four passes were made along the length of the front over a time period of about 80 minutes, the average time interval between landmarks being approximately 11 minutes (660 secs). During each pass sightings were also taken of the individual light stations along Steveston Jetty. Comparison of the calculated positions for each of the stations with actual positions obtained from a 12,000:1 scale map of the area showed average latitude and longitude errors of 2.5 ± 10 m and -2.5 ± 19 m respectively. As was mentioned above, the somewhat increased standard deviation is attributed to the higher aircraft altitude. This may be seen by averaging the target position errors for the first pass over the light stations which was carried out at a lower altitude of 300 m. The averages for these taken alone were -5 ± 5 m and 10 ± 6 m respectively, and are consistent with those obtained in earlier tests.

From the results of the mapping operation (Fig. 5), similar regions of the front can be identified as the plume spreads enabling the velocity of the front in these regions to be approximated from consecutive sightings. These are shown as velocity vectors in Fig. 5. Assuming position errors of ≤ 20 m for each sighting, the error in velocity should be ≤ 0.03 m/sec. As is seen, the major portion of the front moved in a north to northwest direction at velocities ranging from 0.2 to 0.6 m/sec. This movement is against the tidal flow in the strait which is ebbing (≈ 0.25 m/s SE) and can be attributed to the strong SE wind (≈ 14 m/sec) which existed for the duration of the flight.

Various test flights have also been conducted in order to measure surface water currents by monitoring the movement of floating target drogues. The drogues used in these studies were constructed of four foot square sections of $\frac{1}{4}$ inch plywood. Each target drogue was painted fluorescent orange in color and was numbered (0 - 9) on one side such that individual targets in a string could be readily identified from the air by the sight operator. The size of the targets provided reasonably good visibility at an aircraft altitude of 300 m, the altitude flown for these tests. During the initial test flights, the targets were laid along a predetermined line in the study area using a motorized launch. This technique, however, provided no flexibility in that the target line could not be altered during flight in order to take advantage of any obvious physical features. To overcome this problem, it was arranged that the launch would lay the targets in response to instructions given in the aircraft. Communication between the launch and the aircraft was provided by CB

radio and proved to be more than adequate for the range of distances involved (< 6 km).

Several of these test flights were carried out in the fall of 1976 in Haro Strait, a body of water approximately 11 km wide between the lower Vancouver Island mainland and the U.S. San Juan Island. During this time OAS (Pacific) and the U.S. National Oceanic and Atmospheric Administration (NOAA) were also conducting a program of ocean current measurements in Haro Strait providing an opportunity for comparison of current measurements.

Two such test flights were carried out on Sept. 9, 1976 involving two separate target strings in each flight. Monitoring of each target string lasted for about 30 minutes with up to six passes being made over each target in the string. Upon completion of the monitoring of each string, the launch retrieved the targets before commencing to lay the next string. The average time interval between consecutive passes over any one target in any string was about 7 minutes which resulted in a calculated velocity accuracy of ≈ 0.05 m/sec (assuming 10 m accuracy in each target sight). After each pass, the aircraft would continue on to the nearest reference landmark for a position fix. For this particular study area, four surveyed landmarks were available. A map showing the position of the landmarks and the interpolated positions and velocities of each target, for three of the target strings, are shown in Fig. 6. Also given are the positions of the six NOAA current meter stations in the immediate area. It should be mentioned here, that due to the fact that the airborne monitoring encompassed a total time of about 3 hrs, Fig. 6 cannot be interpreted as a surface current record at any one instant of time. Given the tidal conditions that existed during the monitoring period, it is expected, however, that the general features of the flow remained relatively constant.

Current velocity and direction data from each of the NOAA stations was available at various depths ranging from a minimum of 4 m to a maximum of 183 m. The actual depths available from each station in addition to other relevant data are listed in Table I.

TABLE I. NOAA Current monitoring stations in Haro Strait.

Stn #	Latitude	Longitude	Sensor Depth(s) (m)	Water Depth (m)
62	48:27:50	-123:07:02	4.6, 21.3, 184	199.5
63	48:27:12	-123:09:13	4.6, 21.3	141.5
64	48:26:20	-123:12:21	4, 20.7, 72	87.2
101	48:30:40	-123:10:52	12.2	251.6
104	48:30:30	-123:12:26	12.2, 21.3	193.1
105	48:29:51	-123:16:28	4.6, 21.3, 51.2	66.5

Direct comparison of the airborne and NOAA data was made difficult by the fact that no surface current measurements were available at the NOAA stations. Subsurface currents will, in general, differ from surface currents depending on such factors as depth, stratification of the water column and environmental conditions (particularly wind). During the time of both flights (0930 - 1230 hrs) there was a southerly tide and a relatively strong north wind (≈ 5 m/sec). The affect of this wind on the surface current was to increase the velocity depth gradient resulting in a significant difference between surface and subsurface current measurements. This may be seen by considering the data from target line C in Fig. 6. For these data, the target drogue velocities were averaged together for each pass in order to obtain a mean velocity of the water surface (over the area of the target string) as a function of time. Comparison of these data with data from neighboring NOAA stations, near the surface, are shown in Fig. 7. As is evident, the measured mean surface currents are 0.5 - 1.0 m/sec higher than the corresponding NOAA data. Similar results were obtained from target string A. It is evident, however, that the general nature of the flow as measured from the surface drogues is in substantial agreement with the NOAA data taken as a whole.

In addition to surface current measurements, it was hoped that airborne monitoring of floating target drogues could provide useful data on various flow anomalies such as tide lines or eddies. To study this possibility, target

line B was laid across a visible tide line (solid line in Fig. 6) extending from Discovery Island to San Juan Island. Two passes of the aircraft were made over the tide line in order to map its position and relative velocity. The first pass occurred before monitoring of the target drogues in line B began and the second occurred during the monitoring. The position of the tide line was particularly fortuitous in that its direction of motion carried it past two of the NOAA stations (62 and 63). The current velocity and direction data from stations 62 and 63 (for a depth of 4.6 m) is plotted in Fig. 8 as a function of time. As is evident the current velocity and to a lesser extent, the direction, change noticeably as the tide line passes each station. The vertical lines indicate the predicted time at which the tide line passed each station, obtained from the approximate tide line velocity calculated from the two airborne sightings. These predictions correlate well with the actual times of measured current change. The difference in the measured surface currents, from target string B, on either side of the tide line shows reasonable agreement with the same difference obtained from the NOAA data from station 63. Some deviation should be expected, however, due to the fact that the locations of the two target drogues and NOAA station 63 did not coincide exactly. Examining the various velocities, it is seen that the surface velocity of the tide line is intermediate between that of the flows on either side of the line indicating that debris will be swept into the line from both sides, a result which is consistent with general observations of tide line behavior.

6. CONCLUSIONS

A hybrid airborne inertial navigation system comprising a Litton LTN-51 inertial navigation unit and a target sight has been tested for use in aircraft track recovery and airborne mapping of surface targets and/or features. The target sight, which is located in the transparent nose of the aircraft, is used to establish the position drift of the inertial unit at discrete times by fixing the position of the aircraft relative to known surface landmarks. By fitting a modified cubic spline to the discrete drift data, theoretical and experimental tests have shown that the aircraft's track and the position of any additional sighted targets may be determined at any time during the flight to within the RMS error in the individual position fixes provided that these are obtained at least every 10 minutes in time. For the present experimental system, this represents a ground error of about 5 m at an aircraft altitude of 300 m. This error increases for increasing altitudes because of inaccuracies in the target sight and in the barometric altitude indication used. We are currently planning to improve this accuracy with the installation of a precision radar altimeter.

With the accuracies mentioned above, this system is eminently suited for any airborne remote sensing application requiring accurate position information. In the area of coastal oceanography this system has particular application in that the target sight may also be used to monitor the movement of the surface water in a variety of situations. The increased accuracy and flexibility of operation provide real advantages over more conventional oceanographic monitoring techniques such as aerial photography or radar/VLF positioning, and the digital recording simplifies data analysis.

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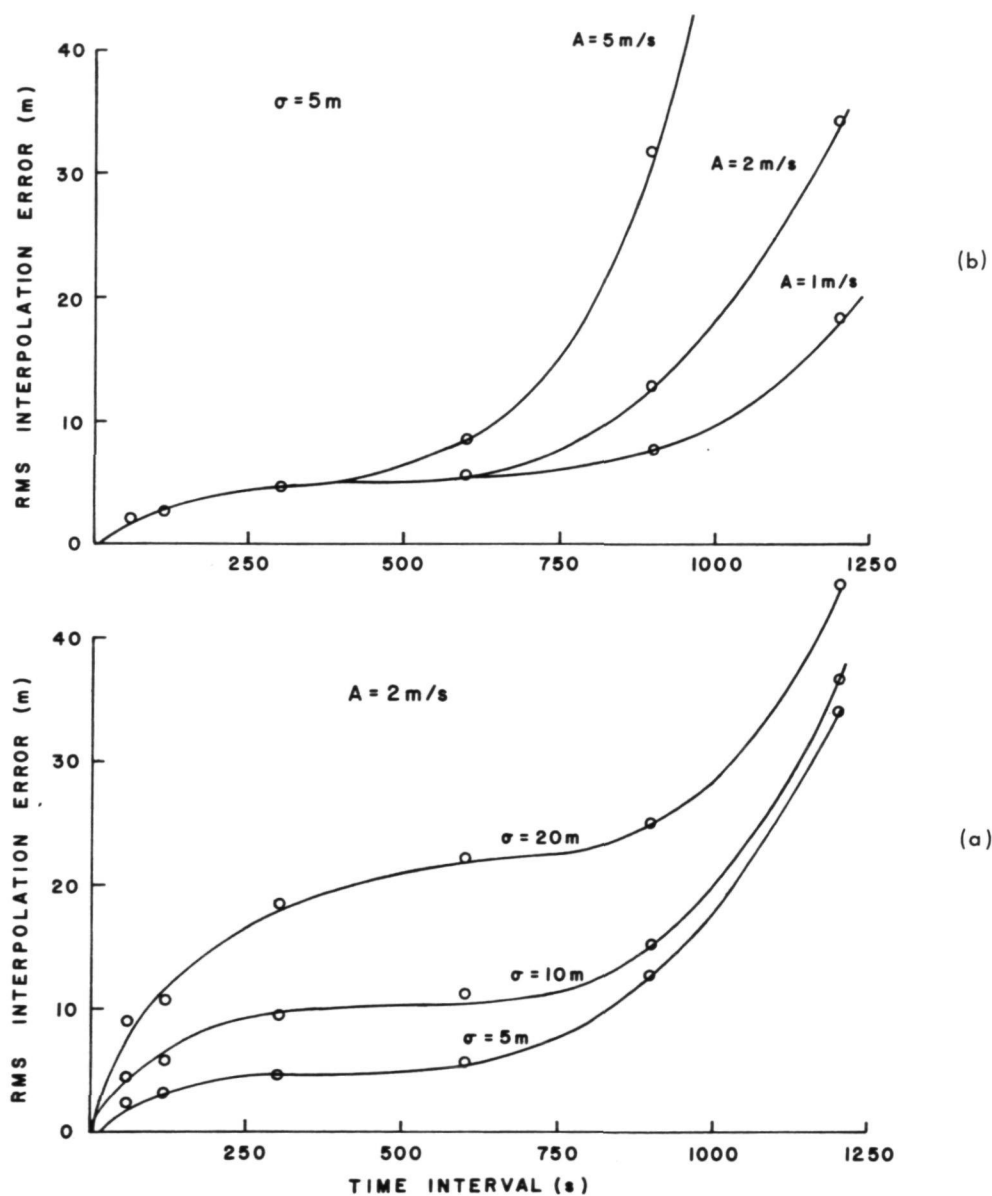


FIGURE 1. ERROR IN FITTING A CUBIC SPLINE TO DISCRETE DATA GENERATED ASSUMING A SINUSOIDAL INERTIAL SYSTEM DRIFT.

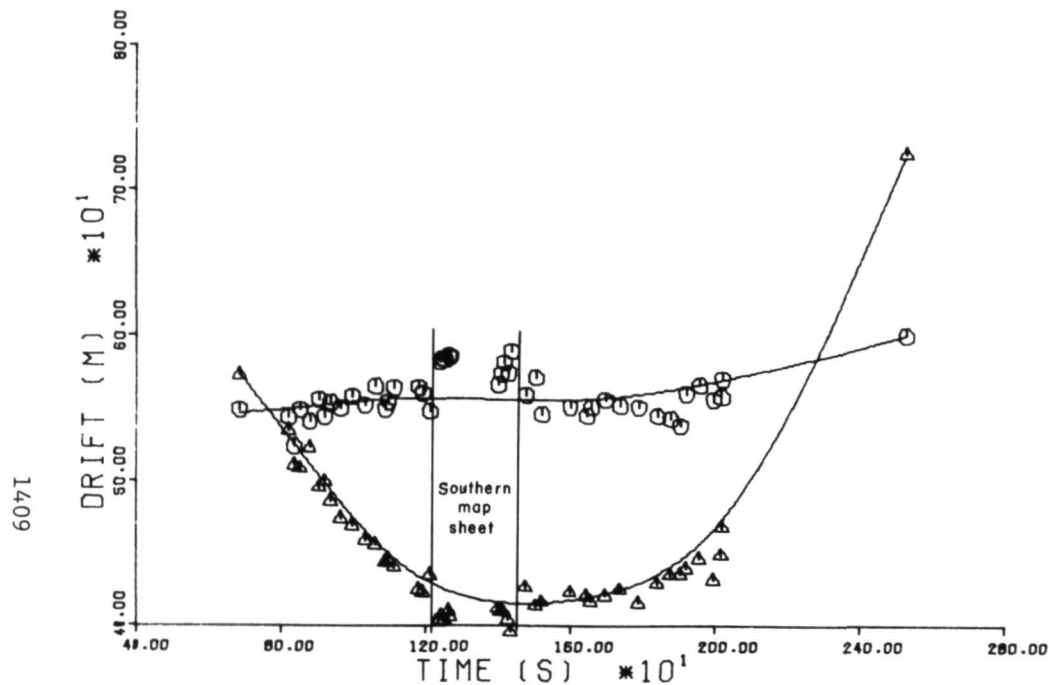


FIGURE 2. INERTIAL SYSTEM DRIFT DURING THE PATRICIA BAY HIGHWAY TEST FLIGHT. The data represents the error in position for major road intersections along the highway. The upper curve is the latitude drift and the lower the longitude drift.

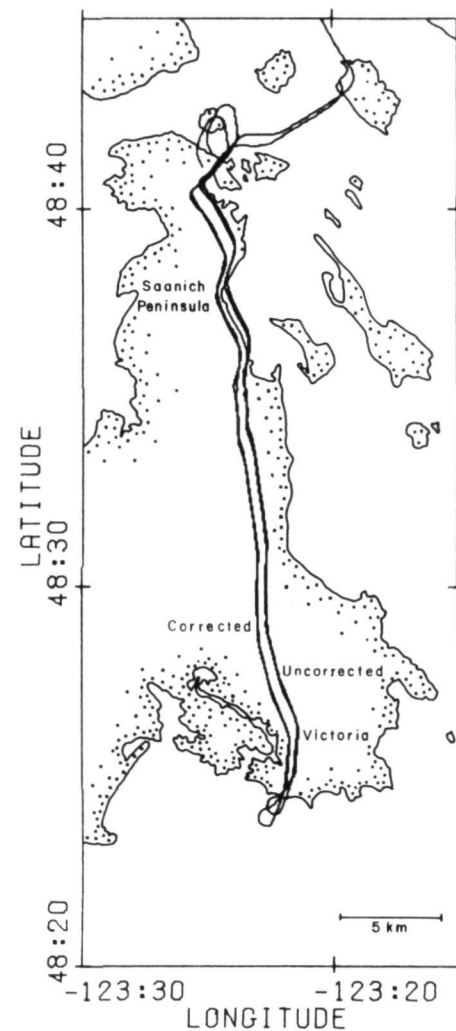


FIGURE 3. MAP OF THE CORRECTED AND UNCORRECTED FLIGHT PATHS FOR THE PATRICIA BAY HIGHWAY TEST FLIGHT.

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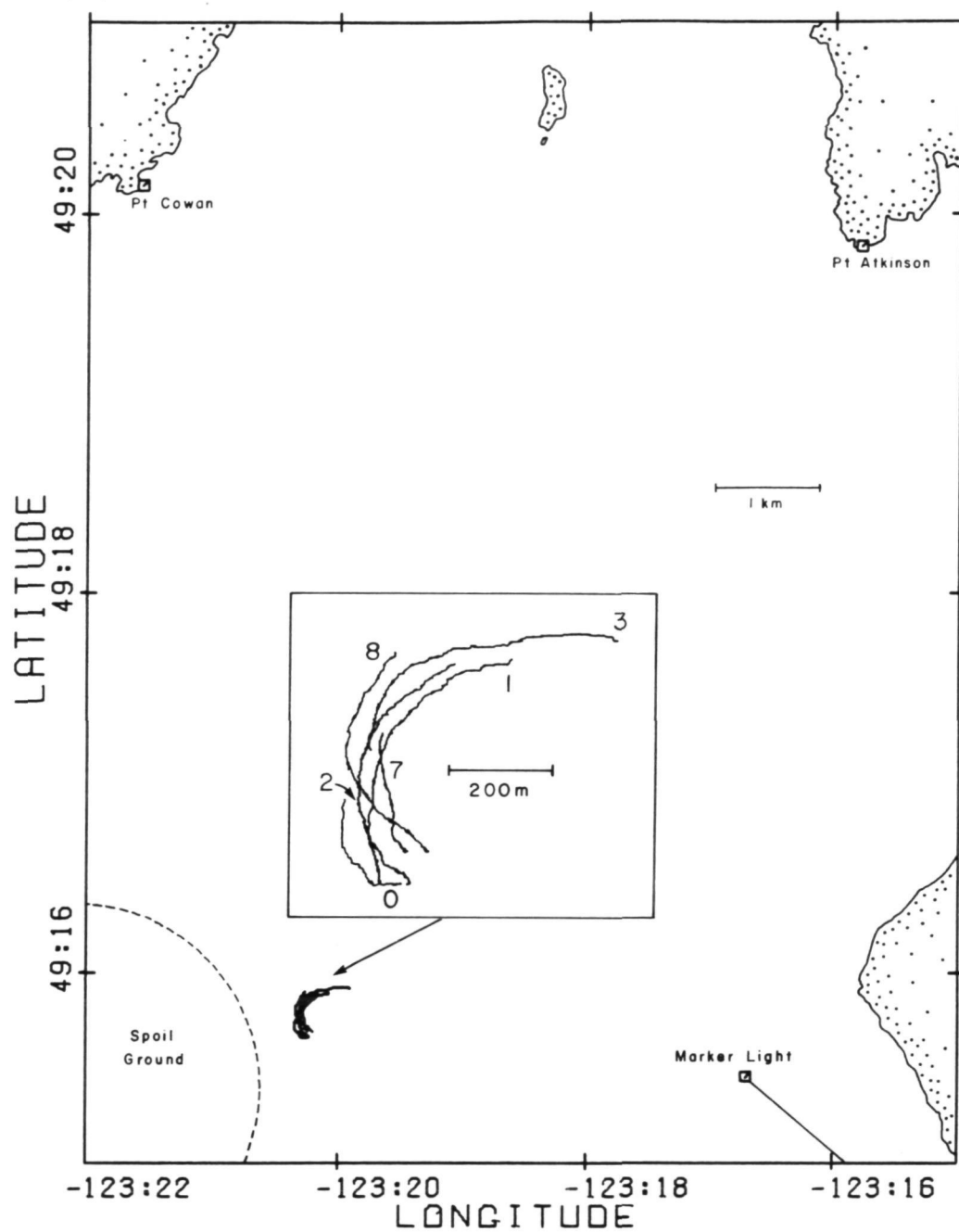


FIGURE 4. MAP OF DUMP MATERIAL FOR THE OCEAN DUMP EXPERIMENT MONITORED ON FEB. 9, 1976. The insert shows an expanded view of the dump material showing the sequential positions for each aircraft pass. The numbers indicate the time of each pass in minutes into the dump.

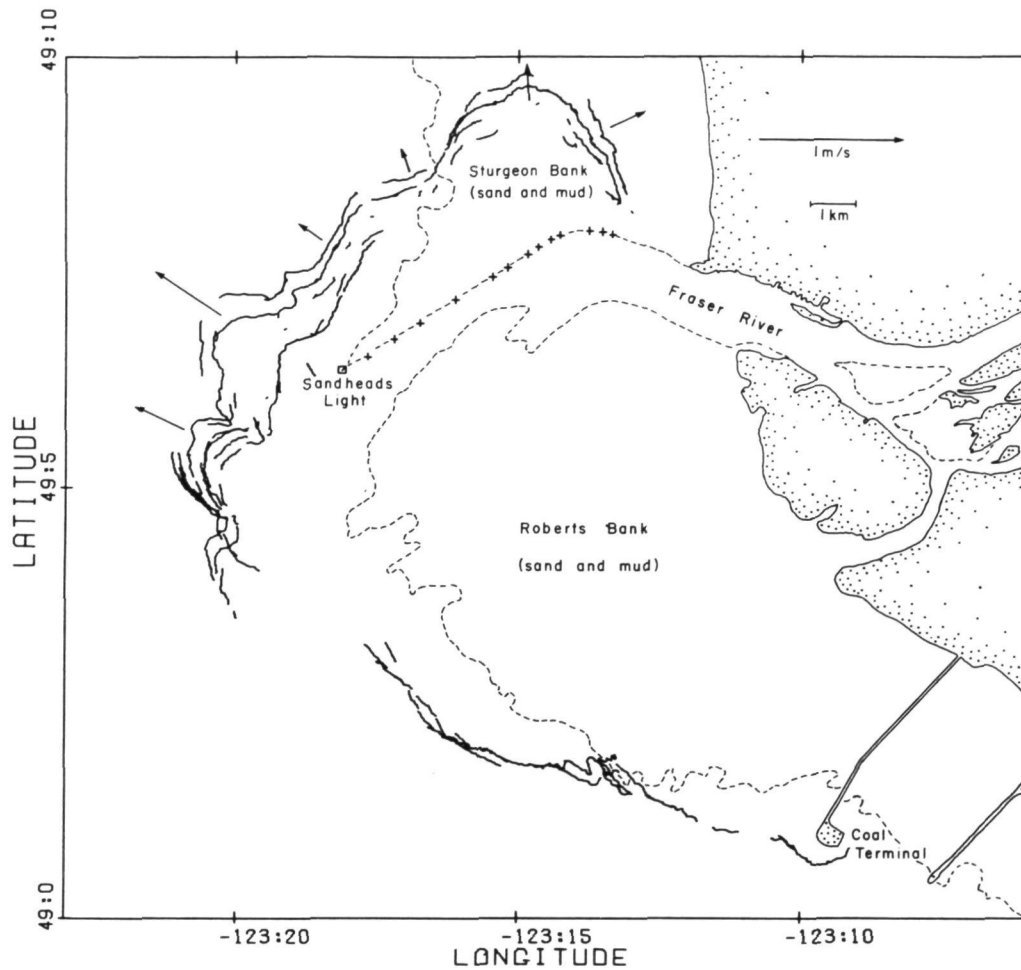


FIGURE 5. MAP SHOWING SEQUENTIAL POSITIONS OF THE SILT PLUME FRONT OFF THE MOUTH OF THE FRASER RIVER NEAR VANCOUVER, B.C. Estimates of the front velocity obtained from the time of each pass are shown as velocity vectors. Also shown are Sandheads light (the reference landmark) and the light stations along Steveston Jetty.

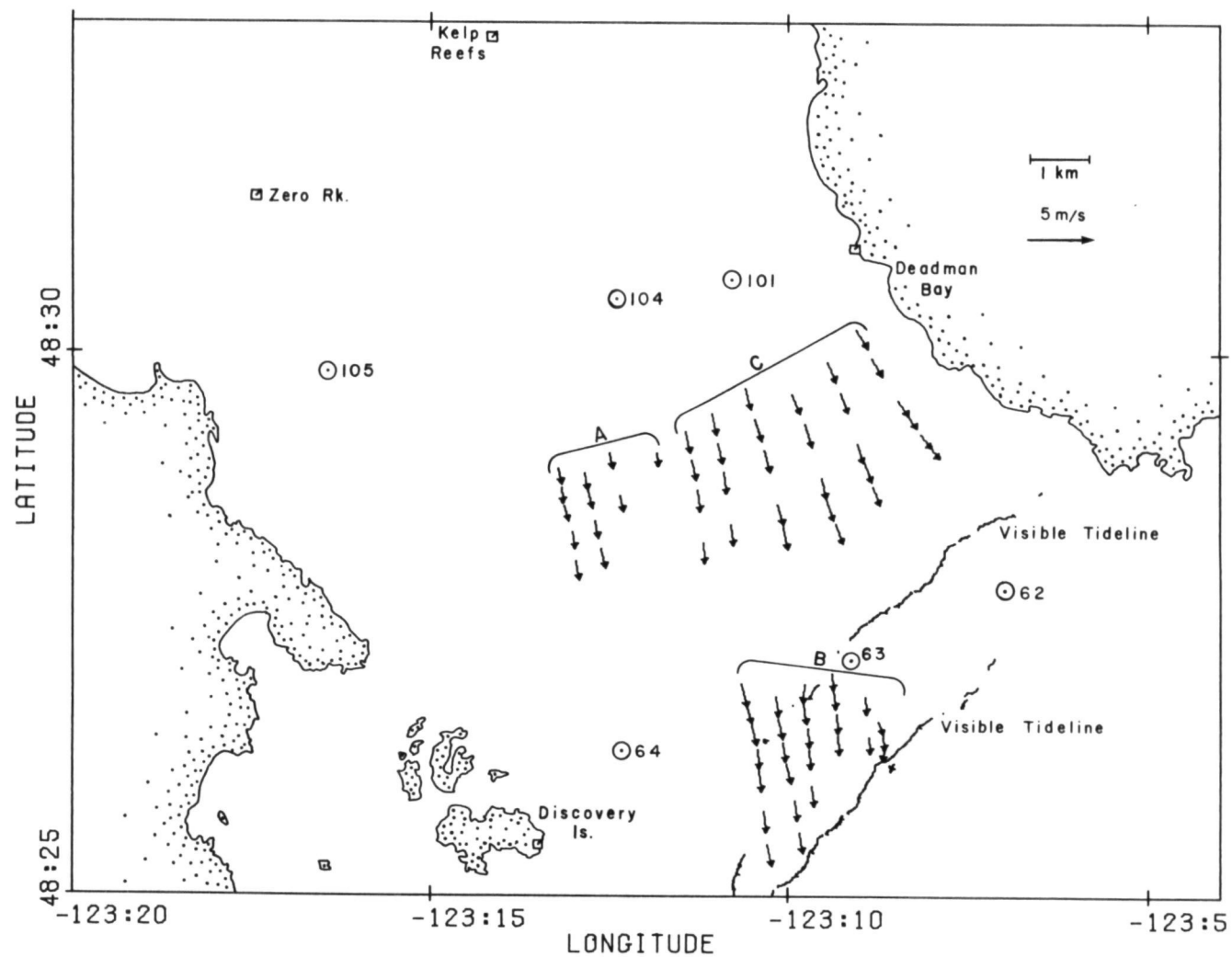


FIGURE 6. DROGUE VELOCITIES IN HARO STRAIT BETWEEN 0930 AND 1230 ON SEPT. 9, 1976. The numbered circles indicate the positions of the six NOAA current meter stations in the study area.

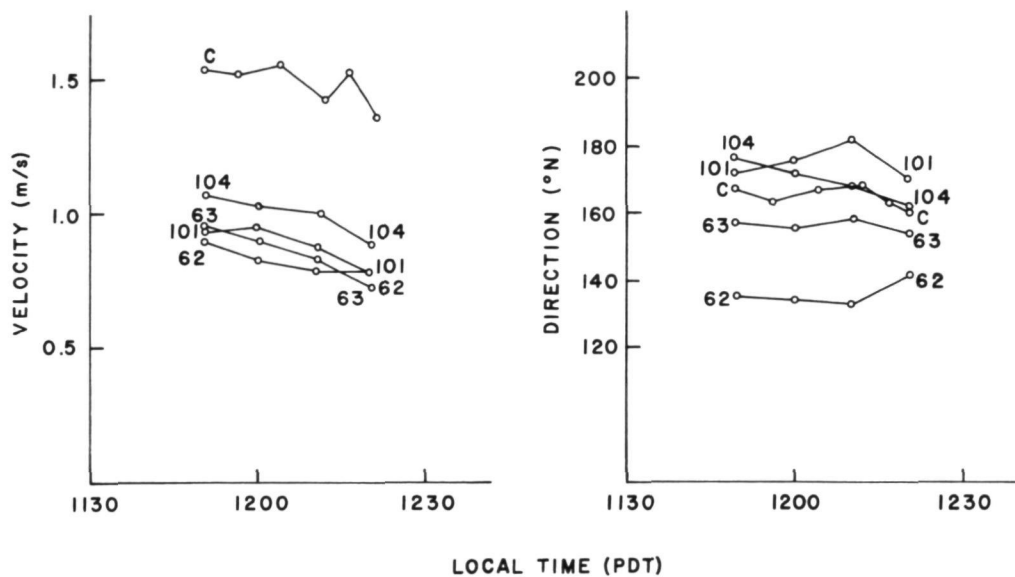


FIGURE 7. COMPARISON OF DROGUE AND NEAR SURFACE NOAA CURRENT DATA. The drogue data is from string C (Figure 6).

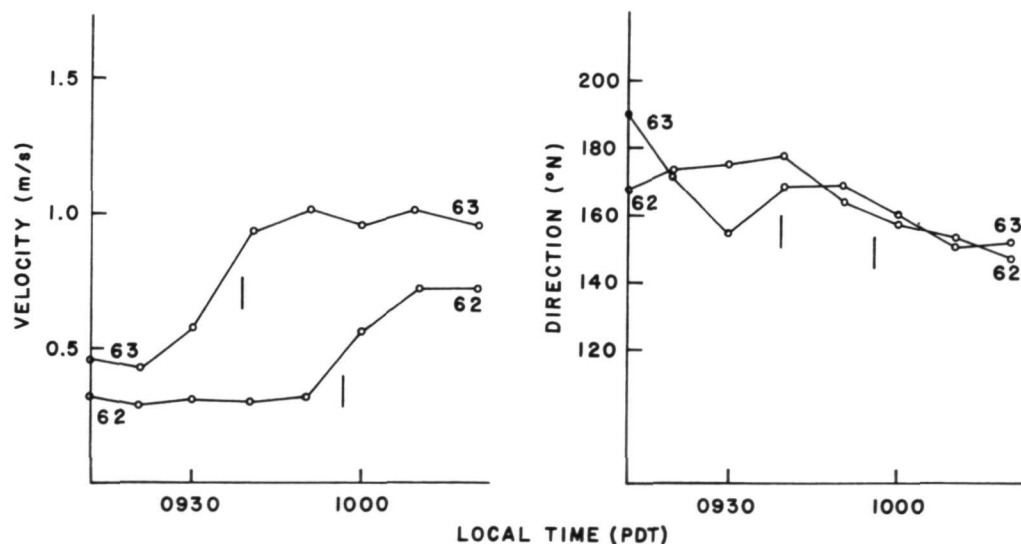


FIGURE 8. NEAR SURFACE CURRENT DATA FROM NOAA STATIONS 62 AND 63. The solid vertical lines indicate the predicted time of crossing of the tide line obtained from the observed tide line velocity.

THE USE OF SYNTHETIC APERTURE RADAR FOR
REMOTE SENSING OF THE OCEANS

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SUMMARY

In the second quarter of 1978, NASA will launch SEASAT-A. One of the instruments on-board this satellite is an L-band imaging radar, which utilizes synthetic aperture radar (SAR) techniques. In December 1975 an experiment was conducted at Marineland, Florida to help the SEASAT Project Office determine the engineering and scientific specifications of the SEASAT SAR. During this experiment excellent fine-resolution wave imagery of near-shore and deep water waves were obtained with the ERIM multichannel SAR system. These wave images were simultaneously obtained at X- and L-band frequencies. At each frequency, the transmitted polarizations were usually horizontal and the received polarizations were horizontal and vertical. However, some vertical transmit data were also collected.

The ERIM multichannel radar data collected at Marineland has been very useful to help establish the minimum signal-to-noise ratio required to discern waves and to independently determine the radar backscatter (radar cross-section density) as a function of depression angle at both X-band and L-band frequencies. A comparison of the image quality obtained at each frequency and at each polarization combination has been made as a function of incidence angle and wave propagation direction.

The Marineland Experiment has demonstrated that SAR is useful for measuring ocean waves by recording wavelength, relative magnitude and position of breaking waves as well as identifying coastal features.

In March of 1976, ERIM collected multichannel SAR imagery of foreign fishing vessels off Georges Bank, Cape Cod. This experiment was conducted to test the potential of a SEASAT type SAR for ocean fisheries surveillance and enforcement. Preliminary results indicate that detection of fish vessels is indeed feasible. A detailed study is currently underway to determine whether SAR imagery is not only useful for detecting but also identifying and classifying fishing vessels. The results of this analysis will also be reported.

Marineland imagery has also been evaluated with respect to various earth applications. Shrimp boats were detected off-shore and coastal marshland with its differing vegetation types were also identified on the imagery. An inland waterway discharge and its resulting shallow water delta are inferred on the X-band imagery by wave patterns on the surface.

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LAKE WATER QUALITY MAPPING
FROM LANDSAT

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1. INTRODUCTION

The University of Wisconsin and Wisconsin state agencies have been engaged in interdisciplinary work on remote sensing of water quality since 1968. Under primarily NASA funding, laboratory, boat level, airborne and satellite analysis has developed to the point where the lakes in three LANDSAT scenes were mapped by the Bendix MDAS multispectral analysis system.

Field checking the maps by three separate individuals revealed approximately 90-95% correct classification for the lake categories selected. Variations between observers was about 5%.

From the MDAS color coded maps the lake with the worst algae problem, was easily located. This lake was closely checked and a pollution source of 100 cows was found in the springs which fed this lake. This report covers the theory, lab work and field work which made it possible for this demonstration project to be a practical lake classification procedure.

2. LAB VERSUS FIELD DATA

To correctly apply remote sensing to lake classification, one must consider factors which do not exist when using remote sensing for classifying vegetation or other non-water features. The specular reflection of the skylight from the water surface is the major factor present with water which is not present with vegetation mapping. This factor can be a considerable value (Piech, 1971). There are other factors such as diffuse reflectance from dirt and foam on the water surface, which add to the total satellite signal. Also in many cases signals from the bottom of the water body are present. However, it is the material in the volume of the water, such as algae, humic material, silt, etc. which causes the backscatter that relates to water quality.

Assuming that there are no bottom signals present, if a very deep clear lake appears on a scene, the strength of the signal from this lake is caused by the surface signals, a small amount of backscatter from the pure water particles themselves and any atmospheric effects. Assume that another lake (Lake #2) contains certain dissolved or suspended impurities that interact with the incoming light. If the signal from the clear lake is subtracted from the signal from Lake #2 the residual signal is only due to the impurities in Lake #2. If this residual is determined at different wavelengths a "satellite residual fingerprint" results for that impurity.

Impurities of a clear lake, of course, are insignificant and the residual fingerprint for a clear lake is flat at about zero across the spectrum. Humic water (sometimes called "brown water", etc.) which is common in northern lakes, absorbs blue energy and has a residual curve which in the blue region dips below that for clear water (a negative value). Algae or silt added to clear water, however, causes increased reflectance and the shape and height of the fingerprint curves can be obtained from both satellite and laboratory data. For laboratory data the values are called "laboratory difference" curves and are determined by manipulating the relative reflectance from a water sample compared to the reflectance from a standard panel. Figures 1 and 2 show "laboratory difference" and "satellite residual" curves for clear water, humic water and heavy algal water.

3. TIME OF YEAR

If one is interested in lake eutrophic classification, then such analysis should be done in late summer when the maximum amount of lake nutrients is converted into algae and lake weeds (biomass). Both algae and lake weeds can be identified from the LANDSAT satellite data.

Figure 3 shows various curves which show that the maximum biomass is produced in the last two weeks of August to the first week in September.

4. LAKE CLASSIFICATION

Satellite residual fingerprints for silt, lake weeds and sand bottom, are unique and can be identified by the computer and printed out in some appropriate color on the lake classification map. In late summer during maximum algal growth the remaining lakes (lakes without silt, weed or bottom signals) will be some combination of clear water, humic water, and algae. These waters can be plotted on a curve such as shown in Figure 4, which is similar to a lake classification scheme originally suggested by Wetzel.

Figure 4 shows four lake types chosen from the map classification scheme used, but more categories are possible. Figures 5, 6 and 7 are profiles across the curve on Figure 4 showing satellite residual fingerprints of various lakes recognized by the MDAS analysis equipment.

All the lakes in the areas mapped were put into one of the following classes:

<u>Class</u>	<u>Color on the Map</u>
deep clear water	Blue
light to medium algae	Blue-Green
medium to heavy algae	Green
humic water or mud bottom with wild rice growing on it	Brown
sand bottom or silt in the water	Yellow
lake weeds	Red
unclassified	Black

For navigation purposes, white and two tones of grey were used for cities, open fields, and woods. Black was used for unclassified areas. More lake categories and colors were initially printed out but it was found that the eye can only reliably distinguish about 10 colors and that too many colors are confusing. Most lakes had different colored pixels within the lake indicating perhaps a sand bar on one end, a weed bed at the other and perhaps even a humic water stream discharging into the lake somewhere else.

5. FIELD CHECKING

The MDAS color coded maps were field checked during the summer of 1975. This was accomplished by aerial observations and ground sampling. Two botony experts and one state DNR lake expert participated in the checking as well as the author.

The two botony experts and the author, took the MDAS hard copy and analyzed each lake as to the appropriate classification of all the pixels within the lake. They concluded that the lake classification was either excellent, good, satisfactory, or unsatisfactory. If the lake was classified as excellent, good or satisfactory, the classification was said to be correct. Each observer took notes separate from the other two. The percent average correct classification for the lakes mapped on the three LANDSAT scenes was 96%, 93% and 92%.

There was about 5% variation between observers doing the checking. It was concluded that the color coded lake classification map was as accurate as any present means of checking it.

6. COWS IN THE SPRINGS OF PRAIRIE LAKE

One will note that for the lakes containing algae (Figure 7) that Prairie Lake had the highest algae fingerprints of all the lakes analyzed. Furthermore the north end of Prairie Lake always indicated a higher algae concentration than the south end.

Low level aerial photos and aerial observations showed that the highest algae concentration was at the mouth of Rice Creek which empties into the north end of Prairie Lake. Further lower level aerial investigations and ground checking revealed about 100 cows in about 70 springs in a small unique wooded area which is the primary headwaters of Rice Creek. Since each cow contributes approximately as much pollution as 10 people, this cattle yard had the approximate pollution equivalent of a community of 1000 people dumping their raw sewage into Rice Creek (see Figures 8, 9, and 10). The citizens of Barron County, Wisconsin, around the Prairie Lake, as a result of the LANDSAT data are taking corrective action with regard to the cows in the springs of Prairie Lake, and hopefully soon the quality of water in Prairie Lake might improve because of the perspective view shown by LANDSAT.

ACKNOWLEDGEMENTS

Acknowledgements are in order to NASA for support under Grants NGL 50-002-127 and NAS 5-20942. Acknowledgement is also due to those personnel who helped administer the grants and to University of Wisconsin, Wisconsin State Agency, Bendix and all other personnel who contributed to this project. Special acknowledgement is expressed to Professor Michael Adams, Dr. Robert Rogers, Professor William Woelkerling and James Thorne for their contributions to the work herein reported.

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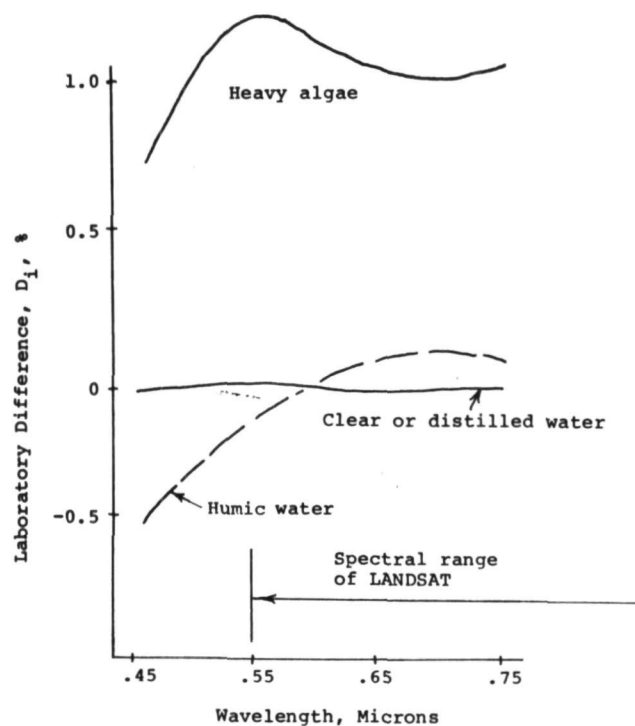


Figure 1. Characteristic laboratory "fingerprints" of two types of material in water. Laboratory difference, $D_i = (\rho_{vi} - \rho_{v1}) / \rho_{PL}$ where ρ_{v1} and ρ_{vi} are the volume reflectance for distilled water and the water in question. ρ_{PL} is the reflectance of a standard panel.

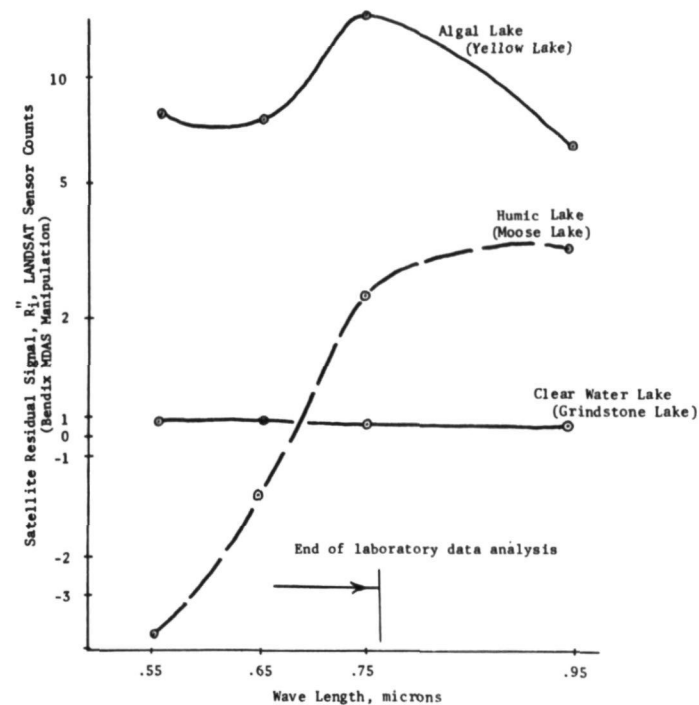
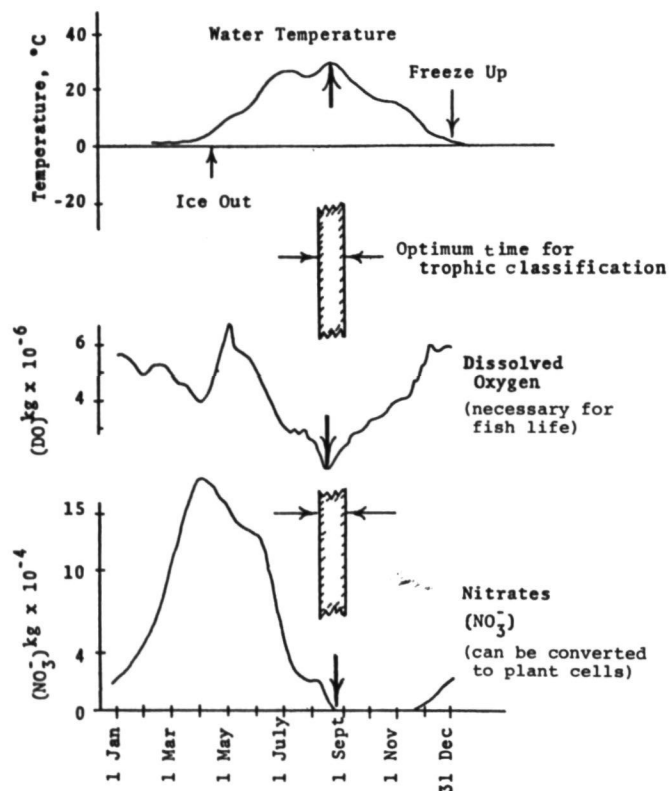
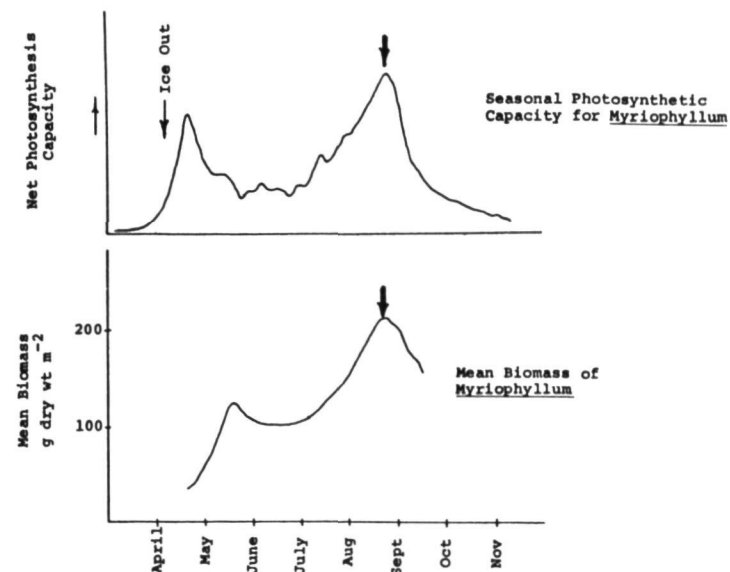


Figure 2. Characteristic fingerprints from satellite residual signal, R_i'' , for the three water types. (From Scherz, Crane and Rogers, 1975).

$R_i'' = (\rho_{vi} - \rho_{v1}) H_o' \frac{\tau}{\pi}$ where H_o' and τ are total irradiance and atmospheric transmittance, respectively.



Water temperature, dissolved oxygen, and nitrates plotted against time. Lake Mendota, 1971. Data from Stauffer, Robert Elihu, Ph.D. thesis, University of Wisconsin, 1974.



Seasonal photosynthetic capacity and mean biomass of Myriophyllum spicatum (rooted lake weed) in Lake Wingra (Madison area lake) in 1971. (Modified from Adams and McCracken, 1974).

Figure 3. Various curves showing that the ideal time for trophic classification of lakes by remote sensing is a several week period in the last part of August to the first part of September.

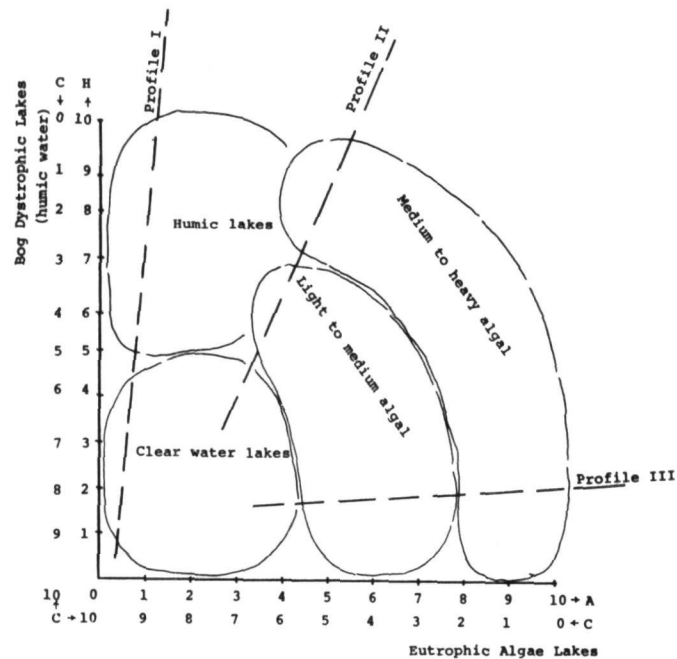


Figure 4. Scheme used to classify lakes from LANDSAT data. This curve is based upon a (non-remote sensing) lake classification scheme originally proposed by Wetzel. Satellite residual fingerprints along profiles I, II, and III are shown in Figures 5, 6 and 7.

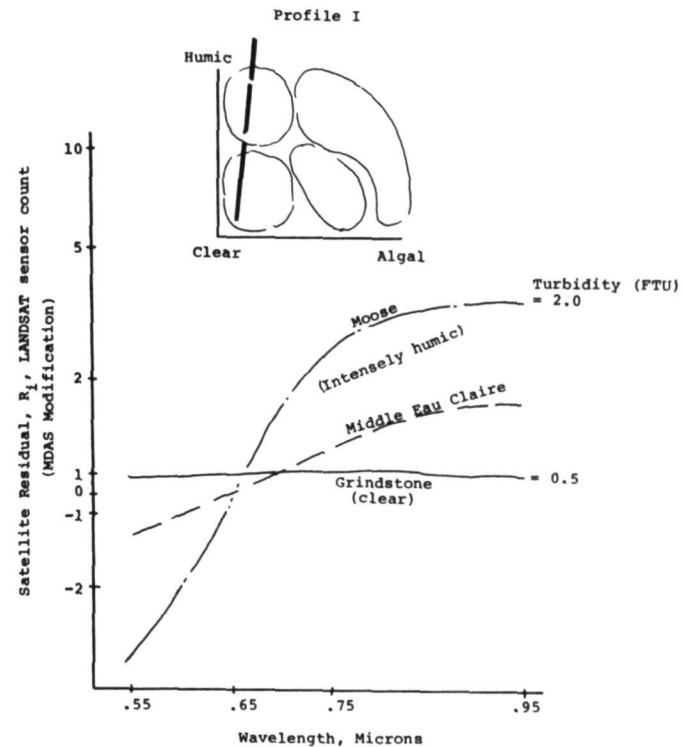


Figure 5. Satellite residual "fingerprints" for clear, moderate and intensely humic lakes (profile I in Figure 4).

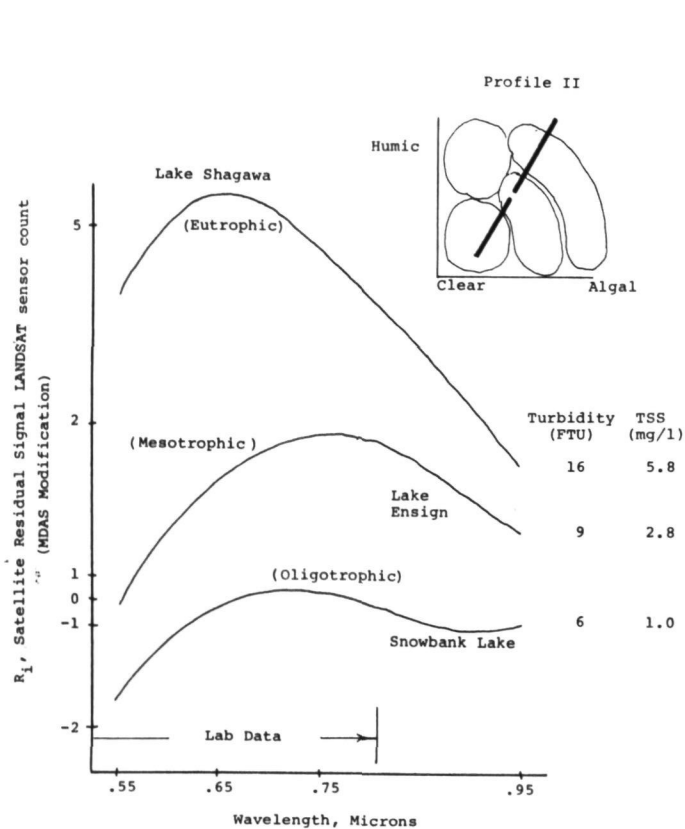


Figure 6. Satellite residual "fingerprints" of moderately humic lakes containing various amounts of algae (profile II in Figure 4). Three lakes near Ely, Minnesota. Shagawa = eutrophic, Ensign = mesotrophic, Snowbank = oligotrophic.

TSS = Total Suspended Solids

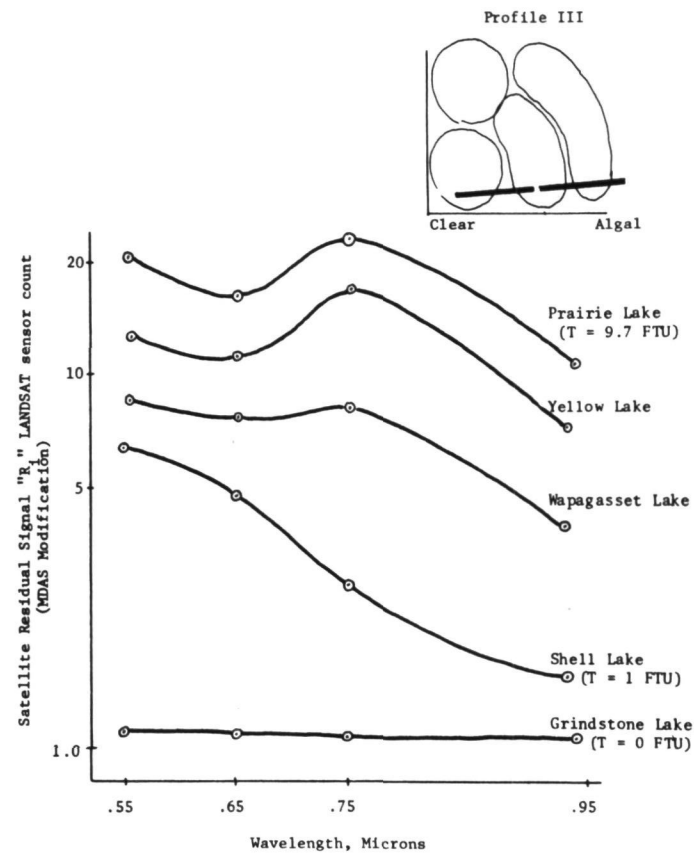
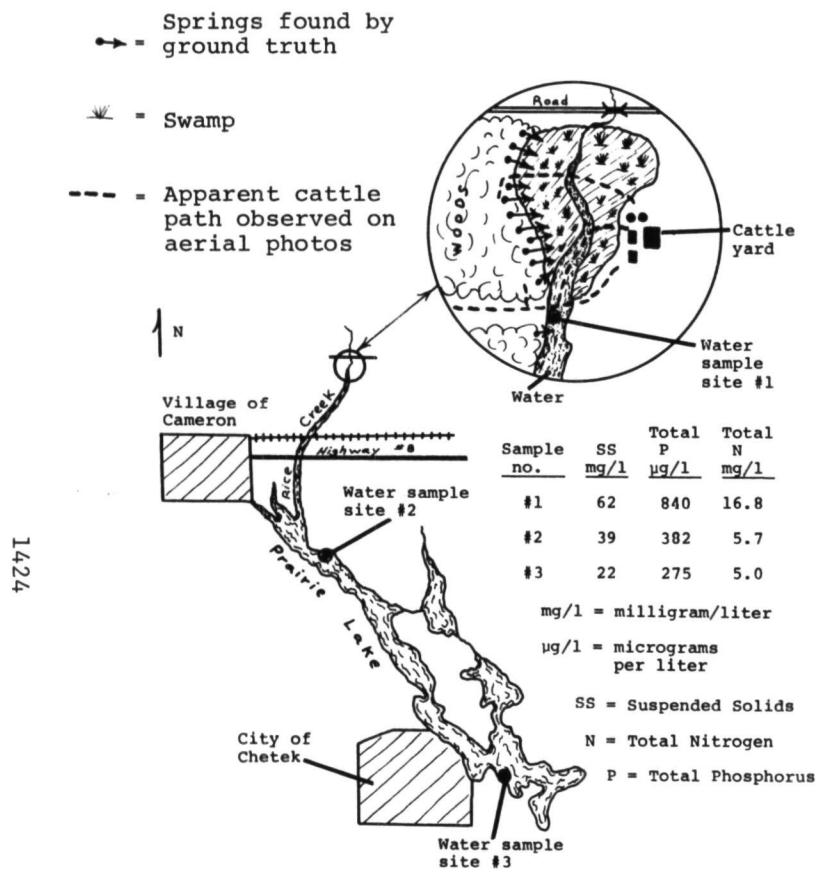
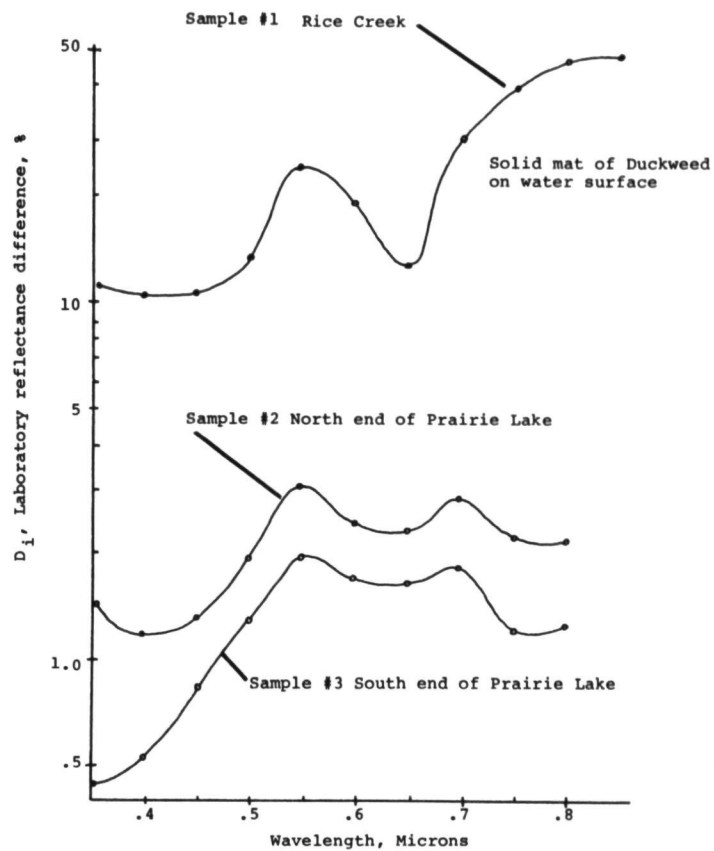


Figure 7. Satellite residual "fingerprints" of non-humic type lakes (Clear water type) containing various amounts of algae. (Profile III in Figure 4). T = turbidity.



Sketch showing Prairie Lake, and cattle yard on Rice Creek.



Laboratory reflectance differences for water samples from Prairie Lake and Rice Creek.

Figure 8. Map and lab data relating to water sample collected from Prairie Lake on 17 August 1976.



Figure 9. A cow in one of the approximately 70 springs which feed Rice Creek.



Figure 10. A view of Rice Creek from Sample Site #1 looking south toward Prairie Lake. A dense mat of duckweed and filamentous algae makes Rice Creek appear as a green field. Total phosphorus concentrations from this water were several times higher than expected from other lakes with serious algal problems. Water from beneath the duckweed had total nitrogen concentrations between 50% and 75% as high as expected from municipal sewers. '

DISSEMINATING TECHNOLOGICAL INFORMATION
ON REMOTE SENSING TO POTENTIAL USERS*

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ABSTRACT

The Laboratory for Applications of Remote Sensing has developed materials and programs which range from short tutorial brochures to post-doctoral research programs which may span several years. To organize both the content and the instructional techniques, a matrix of instructional materials has been conceptualized. Each row in the matrix represents a subject area in remote sensing and each column in the matrix represents a different type media or instructional strategy.

How can technological information be quickly disseminated to potential users in a rapidly expanding field of research? Historically, there has been a significant time lag between technological breakthroughs and the widespread use of new technology. The Laboratory for Applications of Remote Sensing (LARS) at Purdue University is faced with this problem.

LARS is a research facility within the structure of Purdue University. The overall objective of the laboratory is to attack, in an interdisciplinary environment, specific remote sensing problems of current national and world interest in the area of earth resources. A multidisciplinary staff of over 100 professionals and graduate students from 22 departments within the university conducts research, develops computer analysis techniques, explores applications and trains people in the area of numerically oriented remote sensing systems.

Currently one of the major efforts at LARS is to share an understanding of the technology with those addressing natural resources and environmental questions. To train users, a Technology Transfer program area has been established. The staff who handle these educational functions includes experienced educators, training specialists, and instructional developers. The team is responsible for developing educational materials and conducting training programs to transfer remote sensing technology from the research arena to the applications arena.

Since remote sensing is a rapidly expanding field of research, there is a growing need to provide training for graduate and undergraduate students as well as the continuing education of scientists, engineers and users of the associated technology. The scientists and engineers range from those untrained in remote sensing to those already in the field but needing to expand their specialized knowledge and learn about new technological developments. The potential users of the technology are associated with federal, state, city and county agencies as well as business and industry.

Rapid technological developments in remote sensing and the broadening of its use have created a need for educational materials that are relevant and

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up-to-date. Since remote sensing is an interdisciplinary field, the scope of the content to be disseminated is very broad. It ranges from information about the electromagnetic spectrum (physics), numerical analysis techniques (mathematics) and spectral characteristics of vegetation (biology) to specific applications of the technology in fields such as geology, geography, urban planning and agriculture. The types of instructional strategies developed must be diverse in both format and content to meet this need. LARS has developed materials and programs which range from short tutorial brochures to post-doctoral research programs which may span several years. To organize both the content and the instructional techniques, a matrix of instructional materials has been conceptualized (see Figure 1 and References 1 and 2). Each row in the matrix represents a subject area in remote sensing and each column in the matrix represents a different type media or instructional strategy.

The simplest material in the matrix is the FOCUS series which treats basic ideas important in remote sensing. Each pamphlet in the series presents a single concept through several paragraphs of concisely written text supported by illustrations. Care is taken to minimize the use of technical terms in the description and to include definitions where confusion might occur. The two-page pamphlet format is useful because of its portability and flexibility. The pamphlets format also makes them relatively inexpensive to produce and yet attractive to the potential reader. A student typically spends 5 to 10 minutes on these materials.

A very popular and widely used type of instructional materials is the minicourse series. (3) The minicourse series is modularized so that after completing two introductory units, the student may study any of seventeen others presently in the series. Each minicourse includes a set of slides, an audio tape and a printed study guide, and typically requires from 45 to 70 minutes to complete. The student controls the rate and intensity of his study. The student is actively involved in manipulating materials associated with remote sensing, completing exercises and solving problems in the study guide.

A third format involves motion with sound in the form of videotapes. The videotapes produced for LARS "capture" a subject matter specialist discussing an area of remote sensing. Viewing notes have been developed for use with the locally-produced videotapes. Each videotape runs about thirty minutes. For an extended topic, such as pattern recognition, there is a series of videotapes.

Simulation exercises have been designed to lead the student through the professional thought and decision-making processes typical of those required by remote sensing analysts. These units, requiring 3 to 5 hours to complete, illustrate and explain the rationale, decisions and procedures of the professional remote sensing analyst.

Case studies require the student to make his own decisions, specify analysis techniques and interpret analysis results. The case studies usually involve the student using hardware, such as stereoscopic viewers, computers, etc. Intermediate results can be reviewed with a tutor or instructor. Case studies usually require on the order of 10-40 hours to complete.

Using these materials from the matrix, individual training programs can be synthesized. Typically a larger number of units is selected from the left columns with fewer units being selected as the student moves to the right on the matrix. An instructional program can be designed to meet the needs and interests of each individual. When possible, students with the same needs are brought together in small groups of six to eight so that a coordinator of training can encourage group interaction and facilitate discussion of newly learned concepts, principles and procedures. The length of these training programs may vary from half-a-day to several months. Examples of the training programs at LARS include an educational package to train people to use LARSYS (a computer software system), a one-week monthly short course and a visiting scientist program.

An educational package was developed to train people to analyze remotely sensed data using LARSYS, a computer software system. (4) LARSYS software is available through COSMIC or an organization can access LARSYS through the LARS Remote Terminal System. The word "system" is used instead of "network" since

considerable support is provided beyond the basic hardware/software capability. The additional support includes training materials, educational services, extensive software documentation and consultants. The training materials were designed for independent study since organizations getting started in the analysis of remotely sensed data usually have only two or three people making initial use of LARSYS. As their experience and skills improve, other personnel can be trained by them. The individuals usually start at different times and progress at different rates depending upon their background and other duties. Essential to the effective use of the educational package is a tutor with computer analysis experience. Therefore, two people from an organization usually come to LARS for training and they in turn train other people within their organization who train additional staff.

A variety of media and instructional strategies is used in the educational package. The first unit is a programmed textbook. An audio tape, a display book and student notes accompany the second unit. Unit III, a demonstration of a remote terminal, requires an instructor who is familiar with the computer hardware. An outline and suggestions to the instructor are provided along with a set of student notes. During Unit IV, the student gets hands-on experience with the terminal and then completes simple analysis problems in the following unit. The initial training, which requires about 15 to 17 student hours, prepares the student to tackle one of several case studies requiring 40 to 50 hours. These case studies provide a detailed explanation of the philosophy of the analysis methods with an example that parallels the analysis he is to do.

A very effective instructional strategy for training individuals from business, industry and government has proven to be a week-long short course. (5) The short course which is limited to eight to fifteen participants, combines many of the instructional materials already described. For example, the fundamentals of remote sensing are presented by the minicourse series with each participant determining the units which he studies. Videotapes also allow content to be presented by an expert in the field and at the same time free him from having to repeat the same basic presentation each time the course is offered. However, during the short course the expert is usually available for questions and discussions following the videotape.

About one fourth of the short course is devoted to a simulation in which the participants learn the basics of computer-oriented techniques used to analyze remotely sensed data. No prior computer experience is required to gain an understanding of the processes involved. The simulation presents the process in a step-wise sequence and allows the participants to actually make the same decisions an analyst has to make when analyzing remotely sensed data. Computer output is supplied and the results of the participant's decisions are discussed with the teaching staff.

To enable scientists to study remote sensing in depth at the Laboratory for Applications of Remote Sensing, a Visiting Scientist Program has been established. This program provides an opportunity for personalized study at the laboratory during a period of residence which may vary from several days to many months. The instructional portion of the program incorporates media and materials selected from the matrix. In addition, the participants can interact on a one-to-one basis with remote sensing specialists at LARS. The experience is a "reverse consulting" arrangement. Rather than have one consultant come to the person's home institution, the person goes to LARS and has a variety of "experts" available to him along with the supporting hardware (computer, digital display, etc.). The cost of the program is comparable to a daily consulting fee for the first few days of the visit with the daily cost decreasing as the length of the visit increases.

Evaluation is continuous during the development and use of instructional materials at LARS. The materials are used with individual students and their reaction to the material is solicited. On the basis of this feedback, the materials are revised and tested with additional individuals. The materials are then ready for use "in the field" with large groups of students and away from the direct control of the developers. Similar student reaction data is gathered. Usually only minor modifications are necessary at this point in the development sequence. Then the materials are ready for dissemination and use.

When there are changes in either the hardware or software, the materials are updated.

SUMMARY

By working with individuals or small groups, training coordinators at LARS are able to establish objectives for each "student" and to structure the learning program to begin where he is and continue from that point to meet each individual's needs and interests. The Technology Transfer staff has found that systematically designing instructional materials and activities using the matrix as an organizer has proven to be very effective in meeting the needs of students, scientists and users in this rapidly developing technology.

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MATRIX OF INSTRUCTIONAL
MATERIALS IN REMOTE SENSING

			INSTRUCTIONAL MATERIALS				
			FOCUS (10-20 minutes)	Minicourses (45-75 minutes)	Videotapes (30-60 minutes)	Simulations (3-4 hours)	Case Studies (20-40 hours)
Introductory, Basic Concepts			F7	M1, E1	V1		
TOPICS	Physical Basis		Electromagnetic Spectrum Atmospheric Effects Spectral Reflectance Emittance	F10, F14	M2 M2 M2, M3*, M4* M2	V9, V10*, V11* V11*	
	Data Collection	Instruments	Photographic Multispectral Scanners Radar Spectrometers	F1	M9* M8* M10*	V2, V9, V10* V2, V9, V10* V12**	E6**, E7**
		Systems	Mission Planning Airborne Satellite	F8, F12	M5* M6*, M7*	V3** V2 V2	E6** E7**
	Data Analysis Techniques	Images	Photography Scanner Images Radar Images	F9, F12	M13* M15* M14*		
		Computer-Aided	Pattern Recognition LARSYS	F2, F3, F5, F13 F6, F11	E1, M11*, M12** E4*, E5**	V4, V5*, V6**, V7**, V8** V7**, V8**	E2* E2*, E3*
	Applications		Agronomy Forestry Geography Geology Land Use Hydrology	F4, F10	M18* M16* M17* M19*	V13	S1** S2**
							E6** E7** E7** E7** E7**

F=FOCUS Series M=Minicourse Series V=Videotape E=LARSYS Educational Package S=Simulations

Figure 1

1432

ORIGINAL PAGE IS
OF POOR QUALITY

SPACE SHUTTLE SEARCH AND RESCUE EXPERIMENT
USING SYNTHETIC APERTURE RADAR*

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ABSTRACT

Langley Research Center, NASA, is developing a concept for using a spaceborne synthetic aperture radar with passive reflectors for search and rescue applications. The feasibility of a synthetic aperture radar for search and rescue applications has been demonstrated with aircraft experiments. One experiment was conducted using the ERIM four-channel radar and several test sites in the Michigan area. In this test simple corner-reflector targets were successfully imaged. Results from this investigation were positive and indicate that the concept can be used to investigate new approaches focused on the development of a global search and rescue system. An orbital experiment to demonstrate the application of synthetic aperture radar to search and rescue is proposed using the space shuttle.

1. INTRODUCTION/BACKGROUND

A significant search and rescue effort is maintained through the world. U.S. Coast Guard statistics indicate, on the average for the 5 years (1970-1974), 72,000 sortie missions are conducted per year, resulting in saving 4,115 lives per year, and preventing the loss of \$235,570,000 in property per year. However, 1,496 lives are lost per year because timely rescue cannot be achieved [1]. These statistics expand when all search and rescue services are included. Future needs for these services are likely to increase as travel, trade, transportation, and recreation industries expand. Providing for this expanding service will continue to require the expenditures of considerable man-made and natural resources, and will necessitate risk-taking by rescue personnel. The development of a low-cost, low-risk search and rescue system tailored to meet this future growth and need must be a high priority endeavor.

Although current search and rescue efforts are extensive and are executed with dedication and diligence, there is no single system (technology) focused to meet the needs of a broad and expanding user community (aircraft, marine vessels, surface vehicles, and individuals). Search and rescue capability is inadequate and improvements are needed in the areas of: (1) global, all-weather, day or night operations, (2) timely detection of an emergency, (3) location of distress site, (4) identification of shortest path to rescue, and (5) low-cost user hardware.

*Contents of paper given in presentation at WESCON/76.

1.1 BASIC CONCEPT

A new search and rescue concept, originated at the Langley Research Center (NASA), is being pursued to develop needed technology improvements in the previously listed areas [2,3]. The concept (Fig. 1) embodies the use of passive RF reflectors in conjunction with an imaging or side-looking radar (synthetic aperture radar) to detect, identify, and locate the position of users exposed to emergency situations which may require search and rescue. Passive RF reflectors could be carried as standard emergency equipment by aircraft, ships, small boats, terrestrial vehicles, and individuals. The reflectors would be deployed in emergency situations to mark a distress site and to provide a radar target for subsequent detection and use in implementing search and rescue operations. The deployed target is detected and identified and the position is located by an Earth-pointing, Earth-orbiting, synthetic aperture radar maintaining a global scan. The radar provides an image in which the distress target and distress site are visible. In this way, surrounding terrain is mapped and can be analyzed to determine useful and practical ingress and egress routes as an aide in implementing rescue. The radar is operated within the 1- to 10-GHz frequency range. This frequency range is within a radio frequency window and in a frequency region of low RF background noise (Fig. 2); it provides for day or night and all-weather operational search capability.

In an operational system, a set of satellites would be maintained in a polar or near polar Earth orbit. Each satellite would be equipped with synthetic aperture radar and a communication system and would be operated in a search mode throughout successive flight passes over the global surface. Upon the detection of a user's distress target, image data would be generated and transmitted to a rescue operations control center where it would be used to initiate rescue operations. Distress targets would be carried by users and would be deployed in emergencies either by automatic and/or manual means. Targets would be designed to provide large radar backscatter cross sections (σ_t) over a wide range of aspect angles. See Eq. 1, where:

$$\sigma_t > \sigma_o \rho_a \rho_r \quad (1)$$

σ_o = terrain or clutter background radar cross-section density, m^2/m^2

ρ_a = minimum azimuth resolution, m

ρ_r = minimum range resolution, m

The basic concept allows the use of a number of RF reflector types, but the corner reflector is attractive for use as a search and rescue target. It is simple, effective, convenient to store and deploy, and low in cost. One interesting configuration can be fabricated from two basic components (Fig. 3): a Mylar-Saran (or similar nonconducting material) sphere and an internal array of corner reflectors. The reflectors are aluminized Mylar disks arranged into orthogonal planes and attached internally to the sphere. For deployment, the sphere is inflated with helium or hydrogen gas and is tethered by a line anchored at the distress site. This tethering places the target above local obstructions and provides a clear RF field of view for radar detection. In windy conditions, it may be beneficial to tether more than one target on a line to compensate for target motion.

Target deployment can be achieved in a number of ways depending on user needs. In general, these needs would translate into two basic deployment packages: a manual launch canister and a rocket launcher. Each configuration would include an RF reflector, an inflation device, a release mechanism, a tether line, a propulsion unit, and a packing and storage container. Specific targets would be selected and configured, packaged, and deployed as dictated by predetermined user class and expected operational constraints. For example, the target package for explorers and sportsmen would be simplified in comparison with the package designed for commercial airliners or large ships.

The following discussion offers a few examples which explore the basic concept and its practical applications. Once the system achieves target detection, it must be capable of uniquely identifying the detected signal within a processed image as a signal representing a search and rescue distress situation. Three identification approaches appear to be appropriate; that is, can be mechanized with an automaton and are thus suitable for an operational system.

One approach uses a single orbiting radar in conjunction with multiple targets. In this case, multiple targets are arranged in a known geometric configuration. An L-pattern or other configurations such as a linear, circular, or square array could be used. Target spacing would be maintained at three to five times the radar spatial resolution, and the pattern would appear in the radar image for use in recognition and identification. This approach lends itself well to the use of dual polarization radar and the use of digital difference processing to enhance detection.

In a second technique, multiple radars (two or three) would be operated at different transmission frequencies (X- and L- or L- and K_u -bands), would transmit at a single polarization (horizontal), and would receive both vertical and horizontal polarizations. A preselected set of frequencies (F_1 , F_2 , and F_3) and polarizations would be processed to generate three images. Different color filters and intensity levels would be assigned to each image and a composite (superimposed) image would be generated. In this way, false color enhancement is used to aid in target discrimination.

A third technique would employ a matched spatial filter. By using this technique, a single radar image is suitably recorded on film and is used as the input object in an optical processor. Coherent plane wave illumination is then used to transform the spatial variations of the radar image into its Fourier spectrum through a transform lens. Autocorrelation of the object spectrum with a stored matched filter of appropriate design may then be accomplished by performing a second Fourier transform of the light transmitted by the matched filter. At those points where correlation between the object spectrum and matched filter exist, a bright image spot providing the desired target identification is formed.

Once a target has been detected and identified, its position (longitude and latitude) can be determined from one of two basic measurements. One simple method would measure target reflector image position, within the total radar image, relative to any known ground reference point or points (deliberate man-made grid network targets or natural landmark imaged features) appearing in the total radar image. Then, when image scale factors and geographical position of the reference features are known, target location can be calculated. A second method would measure search and rescue target image coordinates within the total radar image relative to a fixed image frame coordinate position. This image coordinate can then be translated into Earth surface longitude and latitude as a function of radar geometry and orbital position (ephemeris data) at the time the radar image was recorded. The radar image is used to locate the position of the target; in addition, the target is imaged together with the natural localized terrain in which it is embedded.

2. SHUTTLE EXPERIMENT

The Space Transportation System (STS) development in progress will provide an unprecedented, timely, and low-cost opportunity to evaluate and demonstrate this search and rescue concept in the real space/Earth environment.

The long-range objective of this technology development experiment is to define and specify an operational low-cost user global search and rescue system structured to meet future demands.

Shorter-ranged objectives include: the development and testing of simple RF reflector user targets including emphasis on configuration, type, size, deployment, array configuration, long shelf life, and low-cost (a number of research reflectors are under development at NASA's LaRC - examples are shown in Figures 4 to 8); specification of radar relative to day-night all-weather operation, frequency selection, polarization, swath width, resolution, antenna, pulse repetition rate, pulse width, chirp modulation, RF power requirements, motion compensation, pointing, and onboard data recording requirements; analysis of data processing to optimize system performance - analysis of detection,

identification and location requirements and isolation of radar processing algorithms; parametric analysis of communication requirements to determine RF link characteristics needed for an operational system; specification of a shuttle experiment using global ground targets representative of the major terrain (background clutter) classes found on Earth; execution of an aircraft flight testing leading to an supporting a shuttle flight test of the basic concept; and the step-by-step definition of an operational system in concert with ongoing development leading to a shuttle experiment. Data from the shuttle experiment is required to support trade studies to augment radar and processing technologies to minimize user hardware cost and complexity.

The technical objective of the shuttle test is to locate special target reflectors and display them together with an imaged terrain map. The utility, limitation, and accuracy of detecting, identifying, and positioning a variety of Earth-located passive reflector targets is to be determined. Also the utility of having surface-image data simultaneously provided with position data is to be demonstrated and evaluated. A comparison of imaging performance among multiple carrier frequencies will be made, and the utility of having wide and narrow swaths with coarse and fine resolutions will be determined.

Primary specifications of the radar for search and rescue applications are: (1) large area coverage mode with wide swath width and range resolution greater than 25 meters, (2) real-time or near real-time alarm when distress reflectors are detected, (3) direct link to rescue organization, (4) multi-wavelength, multi-polarization, and (5) limited swath width mode with resolution approximately 3 meters. A conceptual block diagram for the shuttle experiment search and rescue radar system is given in Figure 9.

Major design considerations for very wide swath capability in an imaging radar include: (1) ambiguity constraints, (2) antenna requirements, (3) transmitter power, (4) pulse synchronization, (5) data rate, and (6) recorder requirements. The system must be designed for multichannel operation. Very wide swath coverage can be realized with multichannel operation utilizing multi-beam antennas as illustrated in Figure 10. Dual swath coverage with overlap (if desired) as illustrated in Figure 11, provides very wide swath width and requires parallel channels for receiving and recording. Isolation between channels and use of a single transmitter can be realized by radiating different frequencies on alternated pulses.

Narrow swath width, fine resolution mode of operation can be obtained by combining the two feeds with signal phasing to illuminate the complete reflector structure. The fine elevation beamwidth will result in greater antenna gain with illumination over a narrow swath.

In an orbiting imaging radar the pulse repetition rate will be constrained by the range-azimuth ambiguity requirements, and transmit-receive isolation requirements. The former can be overcome, within limits, by antenna pattern design. Realizable isolation is independent of antenna pattern and will be determined by propagation delays over the mapped swath. General constraints on the pulse repetition rate can be derived for a given set of radar parameters. Use of dual (but closely spaced) frequency channels will give the capability to operate such subswath somewhat independently.

One operating frequency should be in the 15-18 GHz region. This frequency is a compromise between ambiguity response, atmospheric absorption, and maximum cross section realizable from a given corner reflector. A second lower frequency, 1-4 GHz region, and dual polarization should be included to provide multispectral information. This provides maximum interpretability for determining the nature or conditions of the rescue site (soil moisture, ground cover, etc.)

Problem areas requiring additional research and development include: (1) antenna development to achieve the optimum configuration for both dual beam (wide swath) and narrow beam (fine resolution narrow swath) in a single antenna structure, (2) antenna pointing: use of clutter lock system in the space shuttle radar, (3) basic navigation accuracy, (4) real-time signal and recognition processing, and (5) synchronization and pulse repetition rate controls to insure desired swath coverage.

The experiment is designed to operate with man in-the-loop while shuttle is maintained in orbit as depicted in Figure 12 over a 7- to 14-day duration

in a sortie mode of flight. At least 15 ground sites are selected on a global scale to provide targets in the major classes of terrain in which targets would be embedded. These terrains include oceans, seas, salt lakes, fresh water lakes, ice regions, mountains, tropical forest, desert and semi-desert regions, broad leaf and coniferous forests, grass lands, undifferentiated highlands, and tundra and ice caps [4]. Targets will be deployed at these selected sites and will be imaged on successive overpasses by the onboard shuttle radar. Primary radar signal data will be optically recorded onboard and will be returned after the mission for processing, analysis, and publication and dissemination of results. In addition to onboard data recording, selected image data will be transmitted over a shuttle-to-ground RF link to provide data needed to specify communications requirements for a future operational system. This experiment is being planned for a Shuttle/Spacelab [5] flight in early 1981. A full-scale Spacelab mockup is shown in Figure 13.

RESULTS TO DATE

A number of analytical studies were made and two airborne radar tests were completed - one in Florida in 1973 [3], and one in Michigan in 1975. These tests were designed to evaluate detection and identification. Objectives of the Michigan test were: (1) obtain multi-wavelength radar imagery of reflector configurations situated in various terrain types and (2) obtain radar imagery of different reflector types and configurations for use in recognition experiments. The area imaged during the demonstration flight is shown in Figure 14.

Data obtained from the Michigan test are being analyzed at LaRC and ERIM. For example, two images obtained at 3 cm wavelength, horizontal and vertical polarization, are shown in Figures 15 and 16 for the Temple test site (Site III). Ground site reflector layout is shown in Figure 17. The circular geometry array, the "L" array and the balloon reflectors can be seen on the imagery.

The Michigan data are being analyzed to develop the optimum procedure for the space shuttle test. Similar studies have been made using Florida test data and results are shown in References 3 and 6.

Radar cross-section measurements have been made (in the Environmental Research Institute of Michigan's anechoic chamber) using a number of different types of reflectors. Results obtained are compared with ideal reflectors and are summarized in Table 1. Measured radar cross-section values obtained for both balloons and erectable corner reflectors are less than ideal reflectors of identical dimensions due to construction tolerances.

The circular array used in the Michigan test is attractive for its angularly symmetric geometry. If an array of point scatterers is arranged in an angularly symmetric geometry of a known size, an automatic pattern recognition algorithm can be implemented which does not require an orientation or a size search. One intuitively satisfying geometry consists of a reflective ring with possibly a point reflector located at its center. This geometry is illustrated in Figure 18. This reflective ring would be ideal from an automatic pattern recognition viewpoint, but it would be very difficult to construct with point reflectors. The arrangement shown in Figure 18 represents a practical arrangement of point reflectors such as trihedral corner reflectors.

The signal-to-noise (actually signal-to-clutter) requirement is determined by the clutter characteristics, the desired detection statistics, and the details associated with the reflector array. For the example considered above, the greatest reduction in required signal-to-noise ratio was realized by going from a single reflector element to an array containing only a few elements, namely, seven. Going from 7 to 19 elements only reduced the radar cross-section requirements by approximately a factor of $1/4$ which corresponds to a reduction in corner reflector height by $1/\sqrt{2}$.

The circular array of reflectors is planned for use in the shuttle test; however, additional analysis will be conducted.

Results from aircraft tests and studies have demonstrated the feasibility of the basic concept. A number of inflatable, erectable, and rigid RF targets were developed and have been tested including simple corner reflectors, and radar requirements have been defined and are within the capabilities of today's technology. Both X-band (9.3 GHz) and L-band (1.165 GHz) radars (developed by ERIM [7]) were simultaneously used in testing. Each channel used

horizontal polarization for transmission and simultaneously received horizontal and vertical polarization energy reflected to the transmitting antenna. This provided simultaneous recording of four channels of radar imagery. Test images and data have been analyzed and used for conducting both analog and digital data processing studies. Processing results from this work demonstrate the value of digital difference imagery and false color enhancement algorithms relative to target identification.

Preliminary orbital requirements studies were completed and indicate a circular near polar orbit (inclination of 85.3°) of 470.22 km altitude is most suitable. This orbit is designed to provide total Earth surface coverage every 12.56 hours using three radar equipped satellites. Basic radar geometry to achieve this desirable, approximately 12-hour, coverage includes a swath width of 370 km and a maximum range depression angle of 45° .

Results to date indicate: (1) relatively small circular trihedral corner reflector targets (0.3 m to 0.6 m on edge) positioned in natural terrain, characteristic of many remote areas of the world, can be detected and identified using synthetic aperture radar; (2) radar returns are sensitive to transmitted signal polarization and frequency and this phenomena can be used to structure data processing (digital difference, false color enhancement, composites, and spatial filtering) suited to the unique identification of search and rescue targets; (3) the proper use of target arrays relative to geometry, size, and target types can enhance the identification process; (4) target spacing should be maintained within 1.5 to 2 times minimum radar resolution; (5) reflector target radar cross section should be equal to or greater than the product of minimum radar resolution and terrain background radar cross-section density; (6) it is advantageous to use at least two radars simultaneously having dual polarization receiving capability on each channel; (7) a near polar orbit of approximately 470 km is desirable; (8) depression angle should be about 45° ; and (9) swath width should be at least 370 km to achieve an approximate 12-hour, 100-percent Earth surface coverage. This wide swath-width requirement may be used for a coarse-look mode of operation and may be used in conjunction with a 59-km to 56-km fine-look mode of search.

Study of the basic concept and evaluation of results obtained from aircraft flight tests indicate a multiple frequency, dual polarization, day-night, all-weather, global search and rescue system is feasible. The next logical step is to test and demonstrate the concept in low-Earth orbit using the space shuttle, and work is in progress to carry what has been learned toward a shuttle technology demonstration test flight in early 1981.

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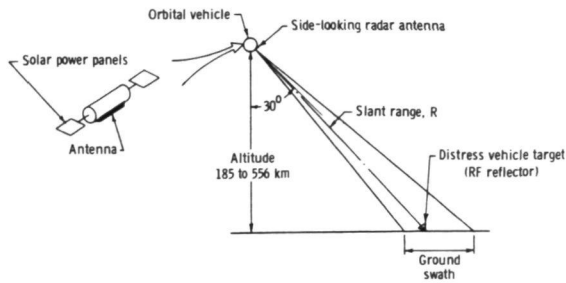


Fig. 1. Global search and rescue basic concept.

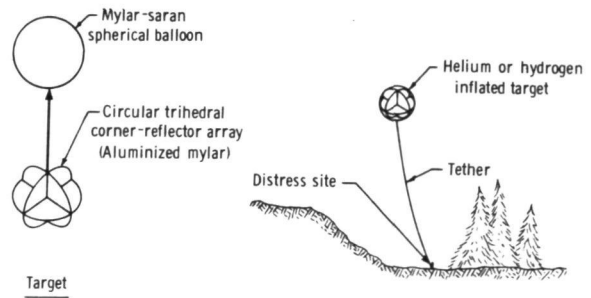


Fig. 3. Search and rescue reflector target concept.

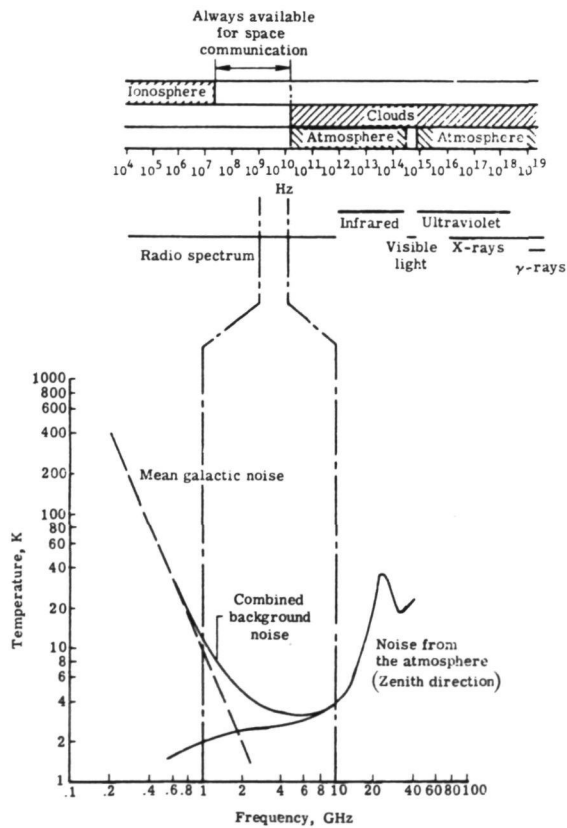


Fig. 2. Frequency window for search and rescue radar.

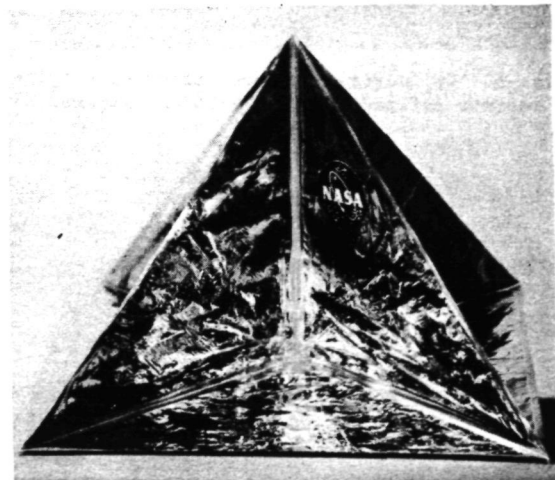


Fig. 4. Pop-up-reflector (four-corner reflector array) 45.4 cm edge.

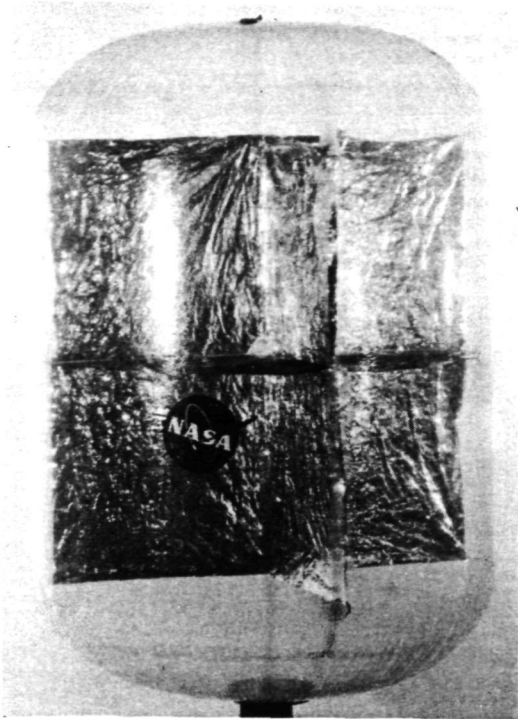


Fig. 5. Cylindrical balloon reflector (eight-corner reflector array) 91.4 cm diameter.

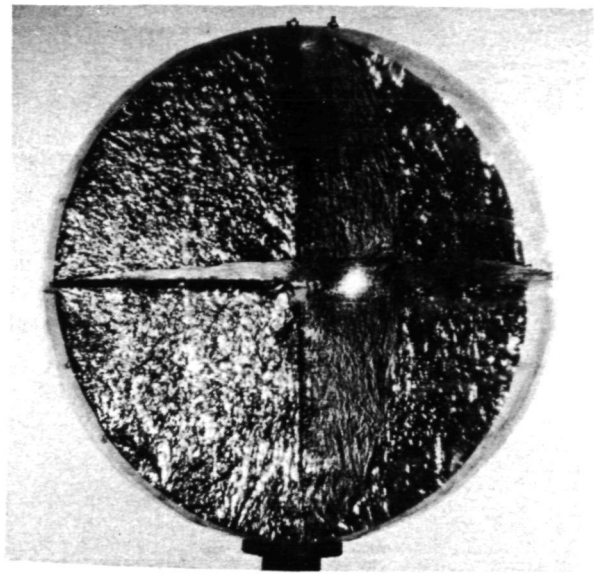


Fig. 7. Spherical balloon reflector (eight-corner reflector array), 91.4 cm diameter.

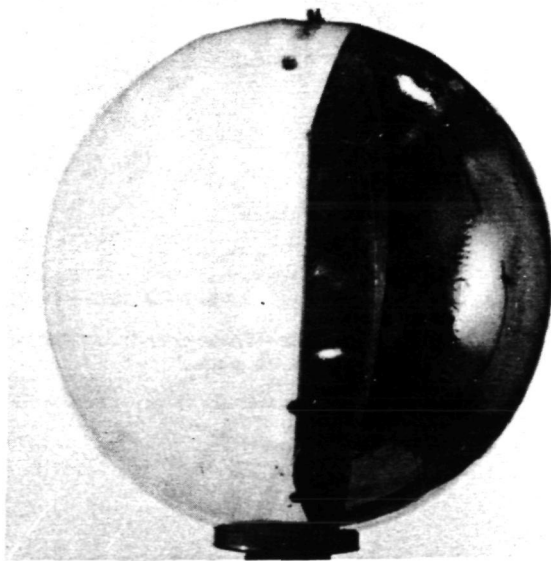


Fig. 6. Hemispherical balloon reflector, 63.5 cm diameter.

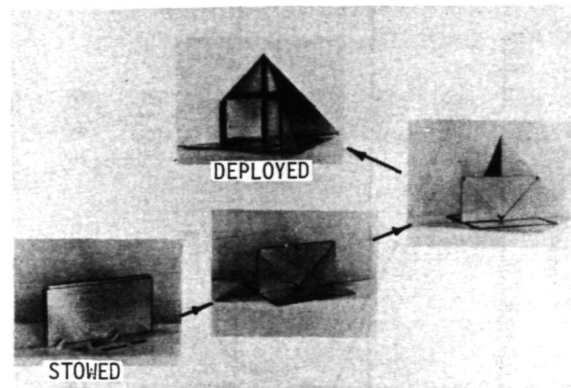


Fig. 8. Poly-fold reflector (four-corner reflector array), 61 cm edge.

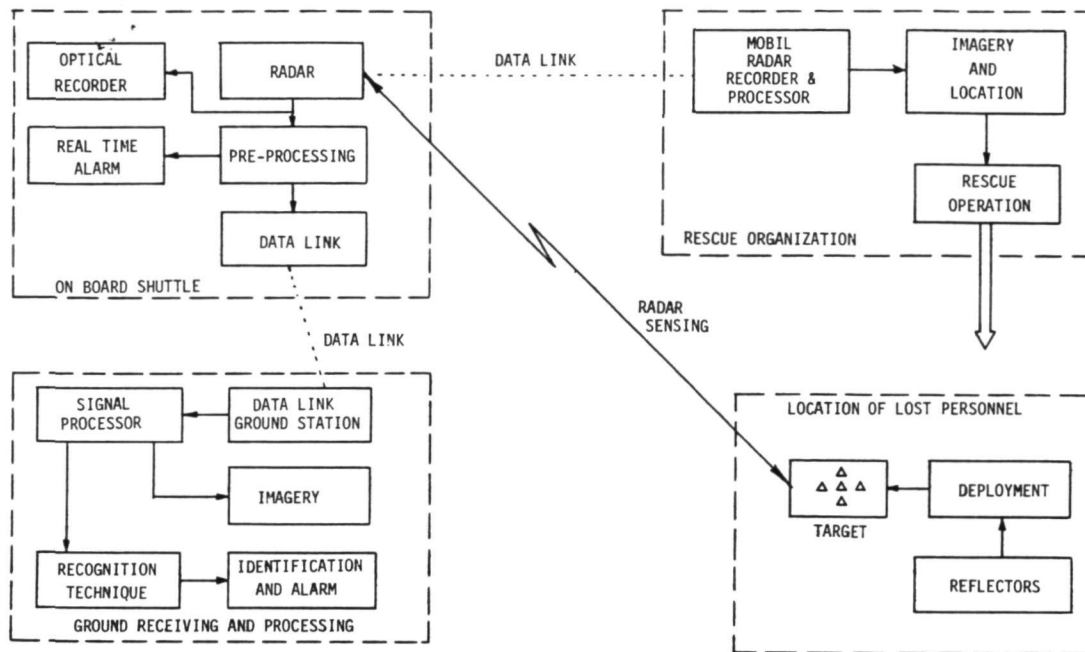


Fig. 9. Shuttle experiment search and rescue radar system - conceptual block diagram.

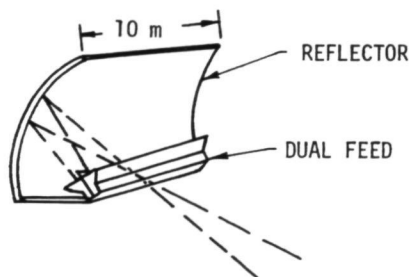


Fig. 10. Dual feed reflector antenna conceptual configuration.

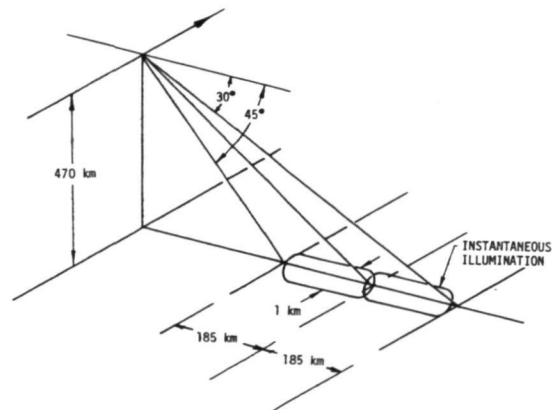


Fig. 11. Wide swath radar coverage geometry - dual beam antenna concept.

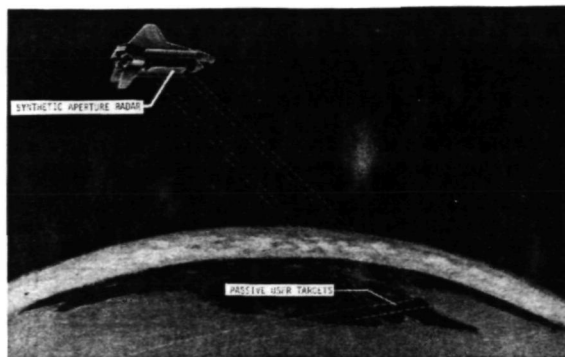


Fig. 12. Search and rescue shuttle experiment - artist concept.

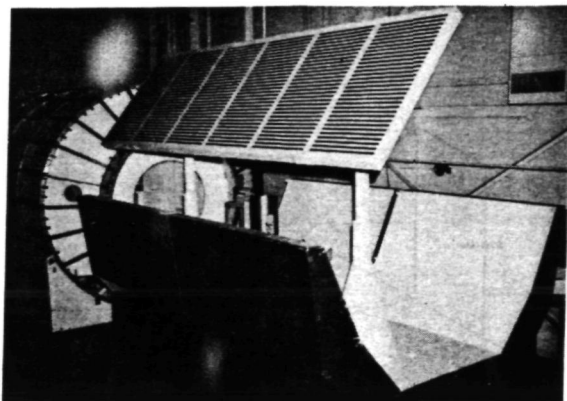


Fig. 13. Search and rescue full-scale mockup of Shuttle/Spacelab experiment.

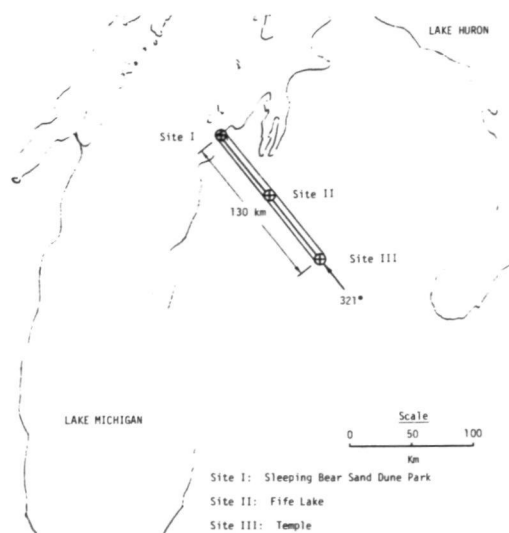


Fig. 14. Michigan search and rescue test area.



Fig. 15. Enlargement of radar image of Michigan Test Site III - horizontal polarization.

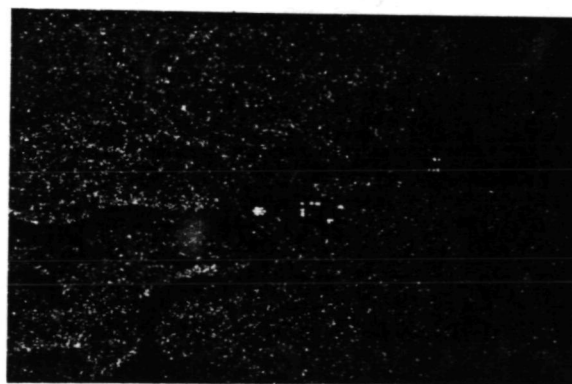


Fig. 16. Enlargement of radar image of Michigan Test Site III - vertical polarization.

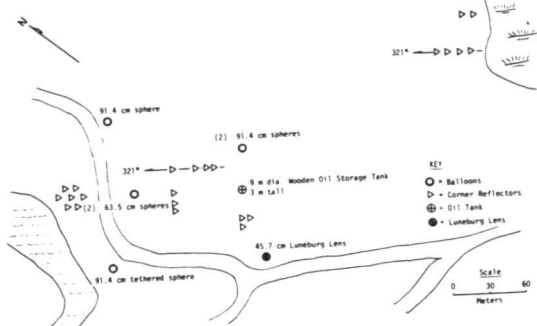
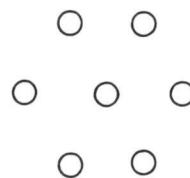
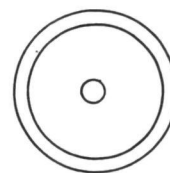


Fig. 17. Michigan Test Site III - reflector layout.



7 Point Reflectors Placed at the Vertices of a Regular Hexagon and at its Center



A Reflective Ring Plus a Reflector at the Center

Fig. 18. Circular reflector array geometry.

TABLE I. - SUMMARY OF BACKSCATTER MEASUREMENTS ON REFLECTORS FOR SEARCH AND RESCUE (9.45 GHz HORIZONTAL POLARIZATION)

REFLECTOR TYPE	AVERAGED MEASURED σ dB*	REMARKS
4 Corner Pop-up		Figure 4
#108	+11.5	Max Value
#103	+18.0	Max Value
#102	+20.4	Max Value
8 Corner - Cylinder		Figure 5
Balloon #101	+24.5	Max Value
#100	+24.0	Max Value
	+11.5	Mean Value
Aluminized Mylar Sheet	+20.5	Smooth Sheet
30.5 cm x 30.5 cm	+18.4	Rough Sheet
Hemisphere Balloons	+15.4	Figure 6
		61 cm Dia.
8 Corner - Sphere		Figure 7
Balloon #107	+21.4	Max Value
#106	+24.7	Max Value
	+11.0	Mean Value
Luneburg Lens		
30.5 cm	+17.0	Max Value
45.7 cm	+22.0	Max Value
61 cm	+24.5	Max Value
Corner Reflector		
45.4 cm	+21.3	A1. Structure Rigid

* 0db = 1 m² Target

PROTOTYPE ACTIVE SCANNER FOR NIGHTTIMEOIL SPILL MAPPING AND CLASSIFICATION

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ABSTRACT

A prototype, active, aerial scanner system has been constructed for nighttime water pollution detection and nighttime multispectral imaging of the ground.

An arc lamp is used to produce the transmitted light and four detector channels provide a multispectral measurement capability. The feasibility of the design concept has been demonstrated by laboratory and flight tests of the prototype system.

1. BACKGROUND

Battelle-Northwest has constructed and operated aerial optical-mechanical scanner systems since 1968. The principal applications of these systems have been thermal infrared (IR) and tracer dye studies of power plant outfalls and multispectral geological surveys. These applications all involved the use of passive scanner systems which depend on sunlight for their operation. In recent years, it has been evident that an active multispectral scanner (that is, one which contains its own light source) would be useful in several remote sensing applications. For example, by stimulating and detecting fluorescent emissions, a system with an internal ultraviolet (UV) light source could potentially detect, map, and classify spills of oils or other fluorescent chemicals at night. Further, passive multispectral measurements and classifications of vegetation and other ground materials are often corrupted by shadows which are seen by the sensor. Because only backscattered light is detected by an active system, active measurements are free of shadow effects. Finally, effects due to variations in the direction and intensity of the illumination tend to be reduced with an active system.

With this motivation we began the development of an active multispectral scanner. The attractive possibility of using lasers to illuminate the ground or water and to stimulate fluorescence was examined, but was rejected because our objective was to develop a small, relatively inexpensive system that could be operated in a light twin-engine aircraft. This objective seemed to be incompatible with the use of lasers at this time. Xenon and mercury-xenon arc lamps were therefore adopted as alternative light sources.

The first flight tests of our prototype active scanner system were conducted in November, 1974. Those tests involved the successful detection and mapping of oil slicks and rhodamine dye in water. Since that time, several other flight tests and related laboratory measurements have been made. Some of the results of those tests are presented below.

2. SCANNER DESIGN

The basic design of the prototype active scanner is shown in Figure 1. As shown in the diagram, the scanner utilizes two reflecting telescopes with a common field of view which is swept across the ground by means of rotating mirrors. This field of view, which is a circular or elliptical spot, is illuminated for nighttime operation by an arc lamp placed at the focal point of the telescope shown on the left side of the scanner. Light reflected or emitted by materials on the ground or on a water surface is focused on the tip of a fiber optics bundle placed at the focal point of the second telescope. The received light is then transmitted via the fiber optics into the detector assembly where it is separated into four spectral bands and detected by photomultiplier tubes.

The scanner can be operated in three modes: 1) An active mode for nighttime imaging of fluorescent materials. In this mode, the UV lines of a mercury-xenon arc lamp are projected onto the ground. The output of the lamp is filtered so that only the UV portion of its spectrum is transmitted. The UV light is blocked in the detectors so that they respond only to the light emitted by the fluorescent material. 2) An active mode for nighttime multispectral imaging of the ground. A xenon arc lamp is used without a source filter to illuminate the field of view. The xenon arc lamp emits a broad continuum of light in the UV to near IR spectral range. 3) The passive mode. With the arc lamp off, the scanner functions as a normal, passive, multispectral scanner.

The outputs of the four channels and a sync signal are illustrated in Figure 1. The sync signal is derived from an optical sensor which detects a timing mark on the rim of the rotating mirror block. The video and sync signals, together with a roll signal produced by a gyro in the nose of the aircraft, are amplified and recorded in analog form on a fourteen-track Sangamo Sabre III tape recorder.

For flight operations, the scanner is mounted on the underside of a Cessna 320 aircraft. It scans in a plane normal to the aircraft flight path and extending 60° to either side of nadir. The relationship of the scanning system to the ground is illustrated in the lower part of Figure 1.

The mercury-xenon and xenon arc lamps used in the active scanner operate at powers of 600 and 700 watts, respectively. The operating voltages and currents are directly compatible with 28-volt aircraft electrical systems. The output spectra of the arc lamps are shown in Figure 2. The transmission curve of the glass filter used in the fluorescence mode is also shown. The emission lines within the UV pass band of the filter contain approximately 30% of the optical energy emitted by the mercury-xenon lamp.

Four photomultiplier tubes with band-pass filters are used to obtain measurements in four spectral bands. A four-branch light guide is a straightforward means of splitting the light collected by the receiver telescope into four equal parts and for transmitting the light to the detectors. However, at least 75% of the light is lost in this method.

An alternative method which offers a potential for better efficiency has been devised. A bifurcated light guide is used to transmit light from the receiver telescope to the interior of a pentagonal cavity. The light enters through a block on one side of the pentagon. An interference filter is mounted flush with the interior wall of each of the other four blocks. The two middle filters in the pentagon are directly illuminated by the two branches of the fiber optics light guide. Wavelengths within the passbands of these two filters are transmitted through the filters and are detected by the photomultiplier tubes mounted directly behind the filters. Wavelengths outside the passbands of the middle filters are reflected toward the other two filters where additional fractions are transmitted and detected. The reflectivity of each of the filters is in the range 80-90% at wavelengths outside its passband. Additional efficiency is derived from reflections within the cavity. Small lenses at the entry ports focus the light on the filters, and the inner surfaces of the top and bottom caps are aluminized glass mirrors. The realized gain in efficiency of this system in comparison with a simple four-branch light guide arrangement has been approximately 50%.

For fluorescence measurements, the optical bandpass characteristics of the filters are selected to cover the range 400-600 nm in approximately four equal parts. For multispectral reflectance imaging of the ground, the filters cover the range 300-900 nm. Figure 2 shows the spectral bands of the detectors in relationship to the output spectra.

The spectral resolution of the prototype scanner is determined primarily by the angular divergence of the output light beam, approximately 10 milliradians. If the aircraft is flying 300 m above the ground, the diameter of the illuminated area at any instant is approximately 3 m.

3. RESULTS

In the first nighttime flight tests of the prototype active scanner system, a two-gallon slick of motor oil was imaged from an altitude of 300 m. The estimated average thickness of the slick was 40 μ m. The left side of Figure 6 shows three intensity-sliced active images of the oil slick. This sequence shows the spreading of the slick over a period of approximately 20 minutes. In another test, Rhodamine B, a fluorescent tracer dye, was imaged from an altitude of 300 m at a concentration of less than 1 ppm.

In August, 1975, the scanner was used in a unique hydraulic model study conducted jointly by the University of California at Berkeley and Battelle-Northwest for the Pacific Gas and Electric Company. The purpose of this study was to examine the behavior of a thermal plume produced by the discharge of cooling water from a nuclear reactor. The active scanner was mounted on a large crane approximately 7 m above the water surface in the test basin. As the crane traversed the basin, two-dimensional tracer dye imagery was acquired. This imagery graphically and quantitatively displayed the dynamic behavior of the plume under the influence of waves and currents in the model sea. Rhodamine B concentrations of less than 5 ppb were readily mapped at scan angles up to $\pm 55^\circ$ and slant ranges up to 12 m. Figure 3 is a set of four images which shows an example of the movement of dye in the plume.

Figure 5 illustrates the results of a flight over a test pond containing a slick of Valvoline 85W140 gear oil. The photograph is an intensity-sliced image of the test pond which was approximately 10 m wide and 20 m long. Oil that had leaked out of the pond onto an underlying concrete slab is visible both above and below the pond. Figure 5 shows a comparison between the fluorescence spectrum of the oil as measured by the scanner in four spectral bands and the spectrum of the oil as measured by a spectrophotometer in the laboratory.

Scanner images of the natural oil seeps in the Santa Barbara Channel were obtained in the passive mode during daylight hours. Good high contrast images of the oil slicks were obtained at altitudes up to 3000 m, the maximum altitude flown.

An example of active, nighttime, reflectance imagery is shown in the right half of Figure 6. This image was produced from bands 1, 2, and 4 (see Figure 2). It is, therefore, similar in spectral character to a normal infrared photograph in which green vegetation is imaged in red. The specularly reflected transmitted light beam is shown where the flight path crossed the Columbia River. In the fluorescence mode, this component is filtered out in the detectors and is not seen.

4. DISCUSSION

A series of laboratory measurements of arc lamp-stimulated oil spectra was conducted to help in assessing the sensitivity of the active scanner for oil spill detection. Fluorescence spectra were measured for 14 crude and refined oils and five other chemicals. These measurements together with flight test results have shown that an operational oil spill mapping and classification capability will be attainable with the construction of a second generation scanner.

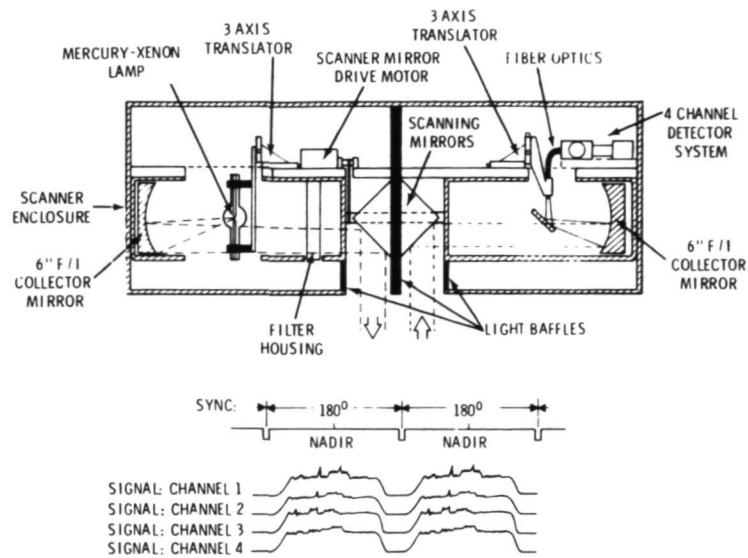
The design concept also appears to be practicable for multispectral imaging of the ground and for spectral classification of vegetation and other ground materials.

At this time we plan to construct a second generation, or operational, version of this scanner and expect to achieve an improvement in sensitivity of at least a factor of 100.

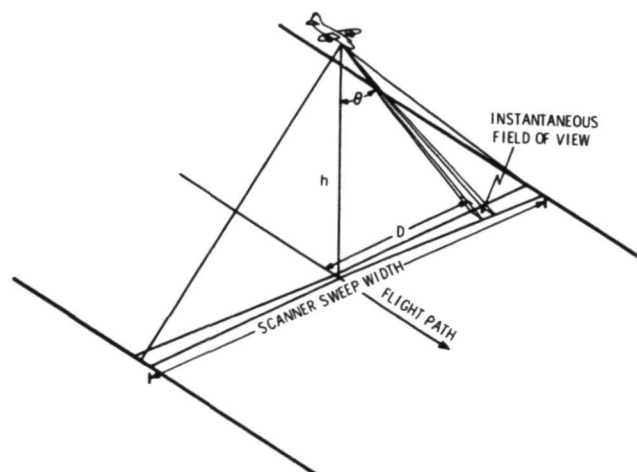
ACKNOWLEDGEMENT

This work was partially supported by the U.S. Environmental Protection Agency, National Environmental Research Center, Remote Sensing Branch, Las Vegas, Nevada and by the U.S. Coast Guard, Office of Research and Development, Washington, DC.

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SCHEMATIC OF OPTICAL-MECHANICAL ACTIVE SCANNER SYSTEM AND SIGNALS
PRODUCED BY THE DETECTORS



IMAGING SYSTEM RELATIONSHIP TO THE GROUND

FIGURE 1.

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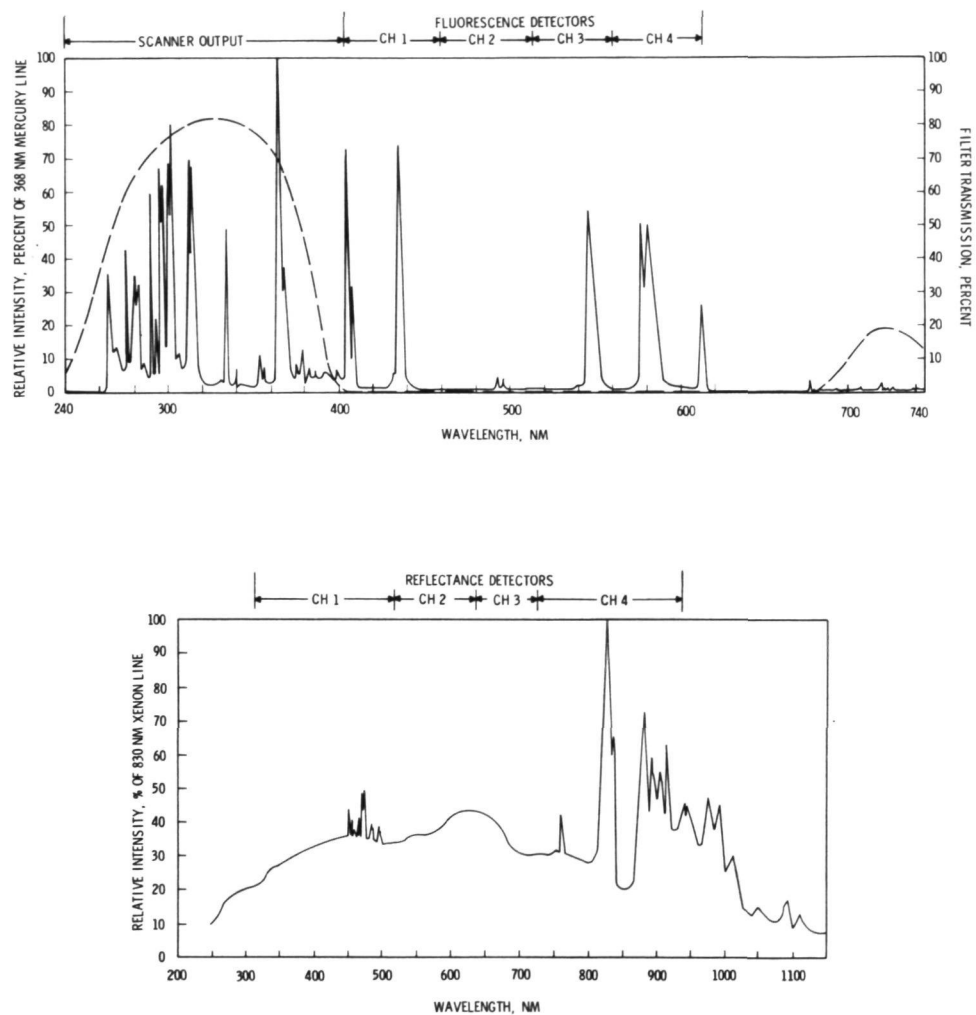


FIGURE 2. ARC LAMP SPECTRA. The upper graph is the spectrum of the mercury-xenon arc lamp. The dashed line is the transmission curve for the UV bandpass filter. The lower graph is the xenon arc lamp spectrum. The wavelengths of the detector bands are also shown.

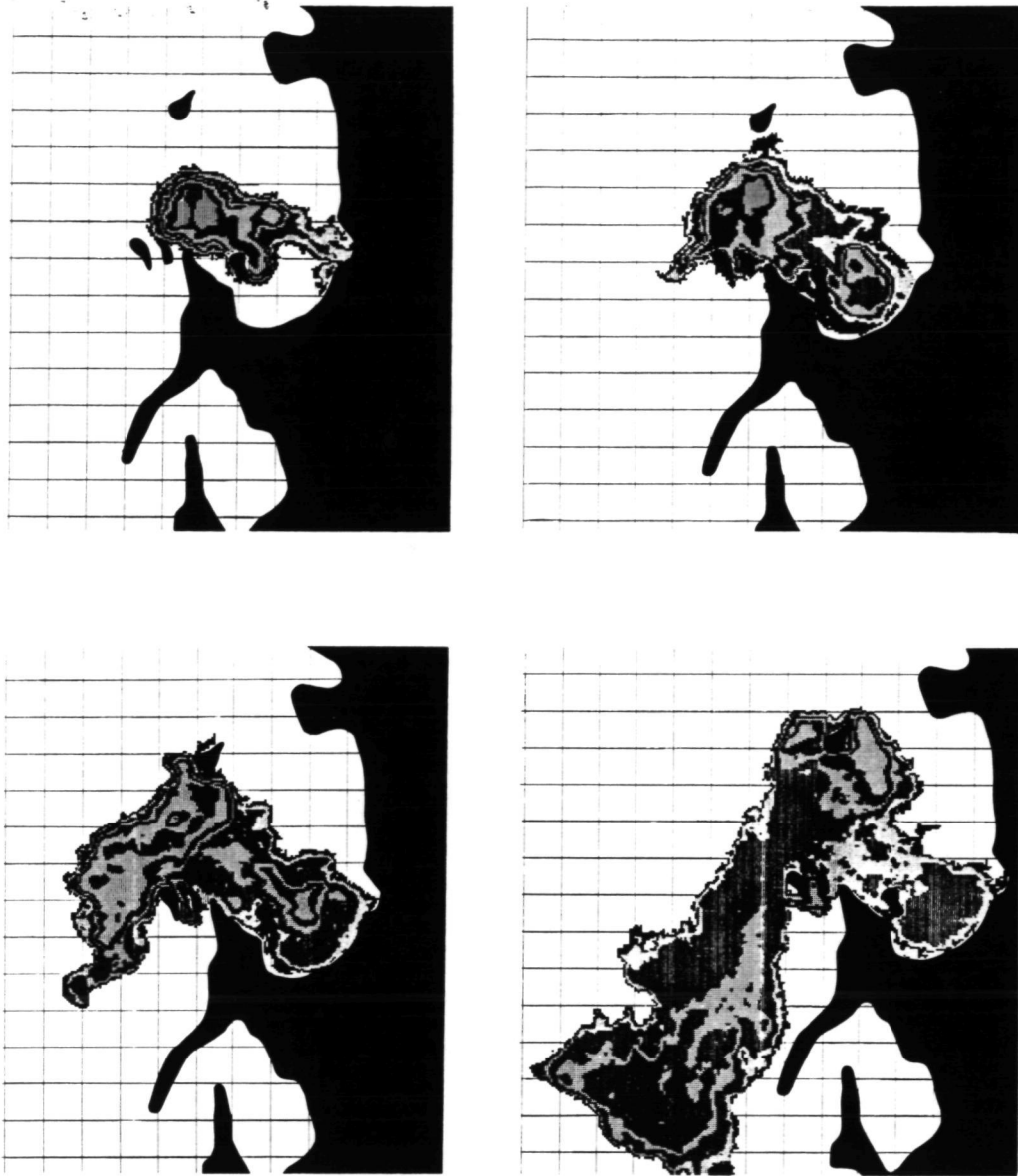


FIGURE 3: HYRAULIC MODEL TEST SEQUENCE. The four pictures show the movement of rhodamine tracer dye in the 1:75 scale cooling water discharge plume of the Diablo Canyon nuclear reactors. Elapsed time is approximately 10 minutes.

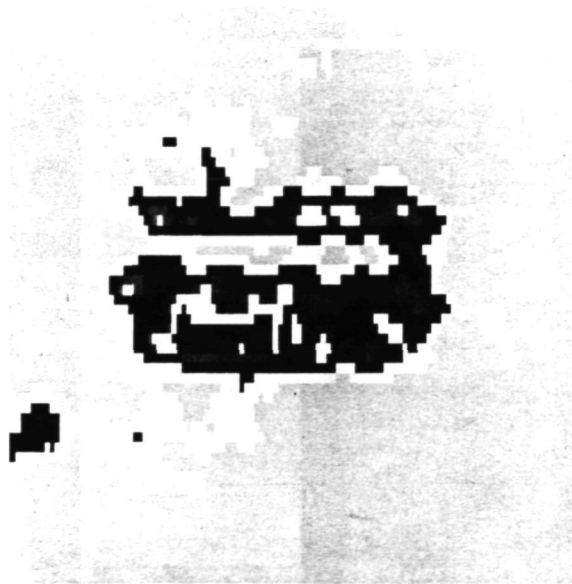


FIGURE 4. OIL IN TEST POND. Intensity sliced active nighttime imagery collected over a test pond. The oil is Valvoline 85w140 gear oil.

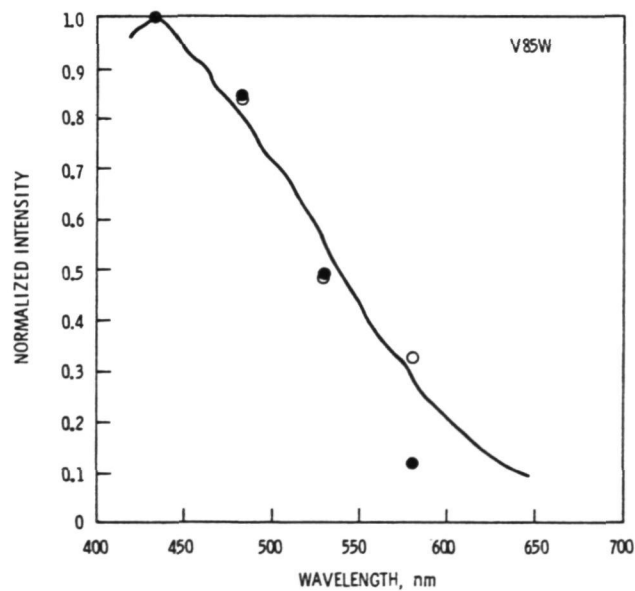


FIGURE 5. OIL FLUORESCENCE SPECTRA. Dots are scanner data measured at an altitude of 110 m. Open circles are scanner data measured at 75 m. Line is laboratory spectrophotometer measurement.

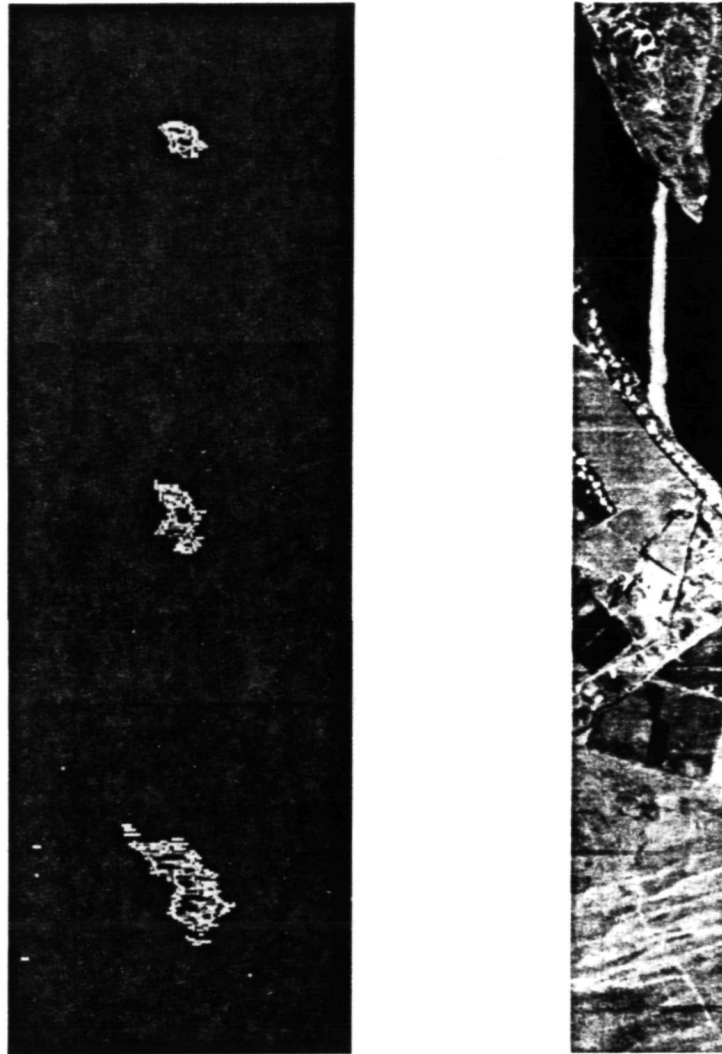


Figure 6. ACTIVE AERIAL SCANNER IMAGERY. The photograph on the left is a series of three nighttime fluorescence images showing the spreading of a 2-gallon oil slick. The scale is approximately 1 cm = 25 m. The picture on the right is a 3-band active image collected at night from an altitude of 300 m. The scale is approximately 1 cm = 200 m.

AIRBORNE MONITORING OF CROP CANOPY TEMPERATURES FOR
IRRIGATION SCHEDULING AND YIELD PREDICTION^{1/}

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Abstract

An aircraft program is being conducted by NASA's Ames Research Center and the USDA's Agricultural Research Service to develop techniques for remotely measuring crop irrigation needs and predicting crop yields. Airborne and ground measurements were made on April 1 and 29, 1976, over a USDA test site consisting mostly of wheat in various stages of water stress, but also including alfalfa and bare soil. These measurements were made to evaluate the feasibility of measuring crop temperatures from aircraft so that a parameter termed "stress degree day", SDD, could be computed. Ground studies have shown that SDD is a valuable indicator of a crop's water needs, and that it can be related to irrigation scheduling and yield. The aircraft measurement program required predawn and afternoon flights coincident with minimum and maximum crop temperatures. Airborne measurements were made with an infrared line scanner and with color IR photography. The scanner data were registered, subtracted, and color-coded to yield pseudo-colored temperature-difference images. Pseudo-colored images reading directly in daily SDD increments were also produced. These maps enable a user to assess plant water status and thus determine irrigation needs and crop yield potentials.

Introduction

Many regions worldwide depend on irrigation for producing crops. Growing populations with expanding agricultural programs will further increase the demand for irrigation water. In fact, the effects of these expanded programs are already being felt in the farm community. In some Arizona agricultural areas, for instance, the water table is dropping nearly 8 feet per year. The cost of pumping water increases as energy costs rise. When faced with drought, such as California has had in the last two years, the problem of water supply becomes particularly acute. Water must be proportioned fairly to all domestic, industrial, and farm users; but, since agriculture is the prime user of water, strict allocation of irrigation water will have a greater conservation impact on total usage than would similar control of either of the other two user groups. Obviously, insufficient irrigation will decrease farm production.

A valuable aid to solving these problems would be a means of more rationally assessing when crops need water, so that they need not be irrigated arbitrarily. Secondly, a means of assessing the yield of crops before harvest would be valuable for planning purposes. If such

techniques could be applied from aircraft or spacecraft, large areas could be assessed in a timely manner.

We have two potential techniques for attaining these goals. They are based upon using the crops' canopy temperature as a direct indication of water stress. The first technique uses the difference between crop canopy and ambient air temperatures at the time of maximum solar heating (1 to 1.5 hours after local solar noon). When a crop has sufficient moisture, it will transpire freely and its temperature will be lower than that of the ambient air; when moisture is insufficient its temperature will be higher than that of the ambient air, due to a reduced transpiration rate. The daily sum of this temperature difference, termed "stress degree day", is the tool used to determine crop irrigation needs and yield potentials.

The second and more purely remote technique does not rely on ambient air temperatures being acquired at the exact crop locations. Indeed, it utilizes the difference between the previously mentioned crop maximum temperature and minimum temperature (just before sunup), which is then normalized by ambient air temperatures acquired from the nearest National Weather Service location. The values are summed daily, thereby producing a value for the stress degree day. Both forms of stress degree day were found to be equally valid in a recent study in Arizona (1, 10). Other investigators have used canopy temperature as an indicator of plant water stress (2, 3, 4, 5, 6, 7, 8, 9).

The major results of Idso, et al (1) can be summarized with the aid of Fig. 1. The cumulative values of stress degree day, SDD, are plotted versus days after planting. Data are presented for four wheat fields irrigated differentially. The sloping line in this figure corresponds to the end of wheat head growth. Actual yield for any field is found by projecting the point of intersection of its SDD curve and the solid sloping line to the upper abscissa. Thus, it is seen that the wheat having the lowest cumulative SDD value also produced the greatest yield.

In view of these promising results, USDA and NASA are cooperating to determine the feasibility of using remote sensing techniques to monitor crop stress. The crops, primarily wheat, were grown by USDA in Phoenix, Arizona. Ground measurements were made by USDA and airborne infrared imagery was acquired and processed by NASA; data were analyzed jointly. The major objective of this study was to determine if temperature measurements made with ground-based instrumentation could be accurately repeated from an aircraft, and to see if the SDD concept was suited to airborne application. The several problems involved in such a program, along with proposed solutions, are also described.

1976 Aircraft Program

Airborne and ground measurements were made at an agricultural test site in Phoenix, Arizona on April 1 and 29, 1976.

OBJECTIVES:

The objective of the aircraft program was to ascertain if infrared techniques developed on the ground for monitoring the water status of crops could be applied from aircraft. Since the ground program had established, or was establishing, the relations between stress degree day and crop irrigation scheduling and yield, the aircraft program was aimed at (1) the airborne measurement of plant canopy temperatures, especially for wheat, (2) the correlation of airborne with ground-based measurements, (3) the detection of wheat under various degrees of water stress by utilizing airborne measurements, and (4) the identification of problem areas associated with airborne measurements of canopy temperature that do not exist for ground measurements.

APPROACH:

The measurement program was conducted on fields of the U.S. Water Conservation Laboratory and the University of Arizona's Cotton Research Center at Phoenix, Arizona. This area is of a homogenous soil type, Avondale loam. The prime measurement area was a centrally located 72-x 90-m section planted in durum wheat. After planting, this section was subdivided into six 72-x 15-m plots, which were irrigated with different amounts of water over the growing season. The irrigation schedule is given in Table 1. Plot 1 was highly stressed, whereas plot 6 was considerably overwatered. Plot 2 received what was considered an optimal amount of water, while the remaining plots, 3, 4, and 5, respectively, received progressively more irrigation. Plots 1 and 3 were subdivided late in the season after experiencing severe water

stress, at which time their south portions received additional water. Surrounding areas were planted with alfalfa and wheat; a portion of the site was bare soil.

AIRCRAFT AND GROUND MEASUREMENT:

Ground-based measurements of plant canopy temperatures were made using Barnes^{2/} PRT-5 Radiation Thermometers. Seven measurements were made at each of two locations in each of the six small wheat fields using radiometers operating in the 8 to 14 micrometer bandpass region. A 20° field-of-view (FOV) radiometer was used to make a straight-down measurement. Measurements were then made with the radiometer aimed at a 45° angle and readings were taken in each of the cardinal compass directions. Next, measurements were made to the north and to the south, near grazing incidence, using a 2° FOV radiometer.

Measurements in the surrounding fields were made using a 20° FOV, 10.5 to 12.5 micron bandpass radiometer. These were made only in the north and south directions with the exception of the alfalfa field just west of the six small wheat plots, where a downward measurement was included.

Airborne measurements were made with a Texas Instruments model RS-25 infrared line scanner, operating in the 8 to 14 micrometer bandpass region. The RS-25 contains two black body calibration sources with platinum-resistance temperature readout. These sources can be heated so as to provide calibration temperatures both above and below those of the scene being viewed. Owing to the predawn surface temperature at flight altitude, this span was not achieved during the morning flights; therefore, all predawn airborne data were adjusted to ground-measured temperatures of a 1.3-m-diameter tank of water and to the temperature of wheat plot 2 south, the optimally irrigated wheat. For consistency, the afternoon aircraft data were also adjusted to the ground-measured temperature of Plot 2 south. The black body temperature span was not altered, and this adjustment in temperature level was less than 2° C, thus probably accounting for atmospheric effects and possible ground instrument drift. The scanner data were recorded on a Sangamo Saber III 14-channel tape recorder. In addition to the scanner, color infrared photography was acquired with a 70-mm Hasselblad camera.

DATA REDUCTION:

The airborne scanner data were recorded in analog form, converted to digital form, and processed using digital image techniques. This processing yielded computer listings of temperature and temperature differences between predawn and afternoon data, pseudo-colored maps of these temperatures and temperature differences, and pseudo-colored maps of daily incremental stress degree day.

The most difficult portion of the data reduction was the registration of the predawn and afternoon data. To provide for registration of the data, twenty-eight 4-foot-square sections of plywood, painted with low-emitting aluminum spray paint, were randomly placed about the test site. These panels served as control points to which the scanner data were "rubber-sheeted".

To computer process the RS-25 scanner data, it was necessary to convert the analog data to a computer-compatible digital format. This was done by inputting the analog signal into an A/D converter using "sample and hold" techniques, which integrate the analog signal for a predetermined period of time. This integrated signal is then measured and a value assigned to represent its relative amplitude. The "sampling" period represents one picture element (or pixel), and the pixel amplitude is converted to a digital value ranging from 0 to 255 (8-bits). The thermal infrared data was processed on an HP-3000 computer system configured with a COMTAL video display, two 1600 BPI tape drives, and a pair of 50 megabyte disk memories. The software program, called IDIMS, acted upon the digital image. Since the RS-25 scanner collects data in a scan line to scan line sequence, each line represents a row in the digital image. Similarly, the selected sample interval for digitizing determines the number of pixels in each scan line. Since each scan line contains the same number of picture elements, the pixels make up the columns in the image array. Eight separate processing steps were used to generate the final output images reported here.

1. Scene Selection. All recorded digital image data were reviewed on the COMTOL display. Thermal calibration, high-frequency image jitter, bad or missing scan lines, image noise and general image appearance were used as selection factors.

2. Scene Reduction. The portion of the scene outside the area of interest was edited out. This conserved processing time.

3. Sweep Distortion Correction. Geometrical distortions caused by the constant angular velocity of the scanner mirror were corrected.

4. Transfer of black body digital values to the reduced scene. This step was required since the position of the calibration signals on the original total scene caused them to be edited out in Step 2, above.

5. Geometric Registration (image to image). To process data between corresponding points on the ground in two different scenes (morning and afternoon), a transformation had to be developed to map pixels in one image to the corresponding pixel in the other image. The aluminum-painted panels were used to do this.

6. Geometric Registration (photo to image). A transformation was next employed to map a base (airborne) photograph to the registered pair of images. Thus, the pixels, approximating the ground truth points on the photograph, were identified.

7. Thermal Calibration. The basic digitized image was created with 256 (8-bit) grey levels. These levels were proportional to the energy received by the RS-25 scanner from each point on the ground. The thermal black body references were also imaged within 256 grey levels, but their temperatures were known. Thus, all image grey levels could be transformed into apparent temperatures by using the black bodies as function generators. The output image, then, has real-valued pixels which represent the apparent temperatures on the ground as seen by the RS-25 scanner.

8. Presentation of Processed Image. Final results were presented in the following forms:

- a. Pseudo-colored video display, where each color represents a discrete temperature interval.
- b. Total scene display or selected areas expanded to fill video screen size.
- c. Line printer output of apparent temperature values or temperature differences.
- d. Single pixel values selected by the operator.

RESULTS

April 1, 1976

On April 1, 1976 the wheat crop had been growing for 120 days and had first headed about 20 days earlier. Plot 1 was suffering from severe lack of water, and appeared very sparse. Plot 3 also appeared sparse, but the remaining plots were of uniform full canopy. The large wheat and alfalfa fields to the south were very healthy. The alfalfa adjoining the small wheat plots, however, was very sparse and irregular because of significant water stress.

Aircraft measurements were made at 5:53 a.m. and 2:06 p.m., local time. Pseudo-colored temperature images resulting from these data are shown in Figs. 2 through 5. Accompanying each figure is a legend designating the temperature spread represented by each color in the figure. Figure 2 shows results of the morning flight. At the time of the overflights, air temperature 150 cm above the ground was 7.2° C at plot 2. From this figure it can be observed that wheat plots 1 and 3 were at ambient air temperature. Temperatures of the other small wheat fields were about 3° to 4° C lower than ambient, which indicates a healthy water status.

The morning scanner measurements of the large wheat field to the south were about a degree less than those of plots 2 and 4 through 6, in nearly exact agreement with ground measurements. Temperature of the large alfalfa field adjacent to the small wheat plots was nearly the same as that of the bare dry soil, but the lush alfalfa to the south of the bare soil had the lowest temperature of all fields, about 7° C below the measured air temperature.

The afternoon-acquired scanner data are shown in Fig. 3. During the time of measurement, air temperature 150 cm above plot 2 was 28.2° C. Figure 3 shows that: (1) the extremely water-stressed plot 1 was as much as 8° C warmer than ambient, (2) the less water-stressed plot 3 was running as much as 6° C warmer than ambient, (3) the better irrigated plots 2 and 4 through 6 were below ambient by as much as 6° C, (4) the lush alfalfa field and the wheat field to the south were identical in temperature, and (5) the bare soil was the hottest of all fields, reaching 14° C above the measured air temperature.

The difference image, derived by subtracting the morning data from the afternoon data, is shown in Fig. 4. The most noticeable features in this image are the very large diurnal temperature variation of the bare soil, and the very small variations of the well-irrigated fields of wheat and alfalfa. The severely water-stressed wheat showed diurnal temperature variations about 10° C greater than the well-irrigated wheat. Table II lists values of daily incremental stress degree days corresponding to the various colors of the plant canopies in Fig. 4. These were computed by the methods of Idso et al (1, 11), where

$$SDD = \frac{(p.m. - a.m.) \text{ crop temperature}}{(p.m. - a.m.) \text{ air temperature}} \times 18 - 18$$

Based on these values, wheat plots 1 and 3 have positive values of SDD, and are therefore considered to be under water stress, as would be concluded from the irrigation schedule of Table I.

As stated in the introduction, an alternate technique for measuring SDD, is to measure the difference between canopy and air temperatures at the time of maximum solar heating. Pseudo-colored imagery maps of these values were produced. A very practical form of presenting this imagery is illustrated in Fig. 5. Here, only positive values indicative of water stress, are displayed for the six small wheat plots. It is readily apparent that plots 1 and 3 are under water stress.

For the correlation studies of airborne-acquired vs. ground-obtained canopy temperatures, the airborne data utilized were computed as the average of the four pixels nearest the estimated points of ground measurement. The results are shown in Table III. The first correlation run was for the six central wheat fields. Since the airborne-acquired data had actually been calibrated by equating airborne- and ground-acquired data over plot 2S and a small water tank, good absolute value agreement in the mean was expected, and indeed, this is what we found, with a correlation coefficient of 0.99. The unknown quantity to be investigated was the amount of scatter in the data, due to unevenness of canopy fullness among the several plots. In this instance, the standard deviation was only 0.7°C .

The next correlation included these same data in a larger group additionally containing results for all of the other wheat, alfalfa, and bare soil fields. Again, a high correlation coefficient of 0.98 was obtained, with a standard deviation of 1.3°C .

The final two correlations to be run dealt with the stress degree day concept as applied to the six central wheat plots. The first utilized airborne-acquired data and compared the two different formulations of the concept, i.e., afternoon canopy-air temperature difference vs. normalized afternoon-early morning canopy temperature difference. The 0.99 correlation coefficient and 0.6°C standard deviation indicated that for the small wheat plots, early morning canopy temperature measurements were perhaps not necessary.

April 29, 1976

As of April 29, 1976, the wheat crop had been growing for 148 days. Figure 6, a color infrared photograph of the fields, shows that the status of the crops varied widely. Plot 1 was under severe water stress. Table I shows that it was irrigated 5 days after planting in December, and that the south portion was irrigated once more 125 days after planting. The bare soil field of April 1 had been recently tilled and planted to cotton which had not yet emerged.

The thermal imagery acquired on the afternoon flight is shown in Fig. 7. Air temperature 150 cm above the ground was measured to be 30.4°C . From this figure it can be deduced that, as compared with measured air temperature: (1) the bare soil temperature was about 20°C higher, (2) temperatures of the lush wheat and alfalfa fields to the south were about 4°C lower, and (3) temperatures of wheat plots 2 and 6 were lower, but those of all others were higher. Another significant feature of these data is that they show a large difference in temperature between the north and south segments of plot 1. This difference was a result of an irrigation to the south segment of April 13. This feature is not detectable on the color IR photography of Fig. 6.

A map of positive values of daily incremental stress degree days analogous to Fig. 5 is presented in Fig. 8 for April 29, 1976. All plots except plots 2 and 6 were under water stress. The magnitude of stress can be determined from the legend.

The same four correlation studies were performed for this day's data as for those of April 1. Corresponding results, Table III, in terms of correlation coefficients and standard deviations in the same order of presentation were 0.95, 1.6°C ; 0.97, 2.0°C ; 0.96, 1.3°C and 0.96, 1.3°C , respectively.

Conclusions

The results of this program demonstrate the potential for monitoring crop irrigation needs and yield potential by airborne infrared techniques. Crop canopy temperature measurements acquired by aircraft appear well adapted to use with the stress degree day concept developed by Idso, Jackson and Reginato (1). For wheat, this technique can now be extended from the ground to aircraft.

The major emphasis in this study was upon wheat. Because all measurements were made after wheat heading, the canopies were full and no confusion existed between canopy and soil back-ground temperatures. Further research is necessary to correlate percent plant cover with airborne-acquired canopy temperatures in the early stages of growth.

The superiority of thermal IR data over color IR photography was clearly established. Water stress undetected in color IR photography was clearly detected in thermal imagery. A value of color IR photography, however, is to establish those fields supporting vegetation. Thus, both techniques used together enhance the strong points of each.

Finally, application of these techniques would be most practical if remote measurements were required only once a day. The results indicate that both techniques could be used with a single remote canopy temperature measurement if simple air temperature transmitters were located in individual fields. It is believed that the afternoon crop minus air temperature technique would provide the most accurate data. Future efforts will be directed toward determining the time-frequency of coverage required to accurately monitor irrigation needs and potential yields.

Acknowledgment

The authors gratefully acknowledge the superb efforts of Ms. Mary Leroy in computer processing most of the data described herein.

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TABLE I. WHEAT IRRIGATION SCHEDULE

Wheat Plot		Days After Planting					
1 N	5						
1 S	5				125		
2	5	83		110	125		146
3 N	5	83					
3 S	5	83			125		146
4	5	83		110			
5	5	83		110	125		
6	5	83	99	110	125	132	146

TABLE II. STRESS DEGREE DAY VALUES FOR PSEUDO-COLORED IMAGE OF FIG. 4

Color	(P.M. - A.M.) Normalized
	Stress Degree Day
Lt. Green	6.9 - 8.7
Dk. Green	4.4 - 6.1
Lt. Blue	1.8 - 3.5
Dk. Blue	(-0.8) - 0.9
Violet	(-3.4) - (-1.7)
Black	(-6.0) - (-4.2)

TABLE III. CORRELATION STUDY RESULTS

Factors Correlated	Correlation Coef.		Std. Deviation, °C	
	Apr 1, 1976	Apr 29, 1976	Apr 1, 1976	Apr 29, 1976
Airborne vs. Ground Canopy Temps for 6 Wheat Fields	0.99	0.95	0.7	1.6
Airborne vs. Ground Canopy Temps for All Fields	0.98	0.97	1.3	2.0
Two Airborne Techniques for Determining SDD	0.99	0.96	0.6	1.3
Airborne p.m. - a.m. Canopy Temp Difference vs. p.m. Canopy Temp - a.m. Air Temp	0.99	0.96	0.6	1.3

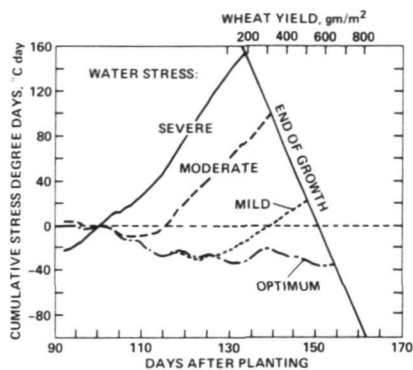


Figure 1. Stress Degree Day vs Days after wheat planting and vs yield. Adapted from (1).

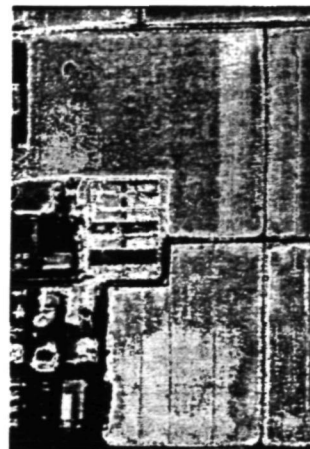


Figure 2. Pseudo-colored thermal imagery of the Phoenix test site acquired at 5:53 A.M., April 1, 1976. The six differentially-irrigated wheat plots appear in the center and are identified as 1 through 6 going from bottom to top, which is west to east. Bare soil adjoins these plots to the east and alfalfa to the west. South of the bare soil is another field of alfalfa; and west of it is another field of wheat.

	°C
Red	6-7
Orange	5-6
Violet	4-5
Yellow	3-4
Green	2-3
Lt. Blue	1-2
Md. Blue	0-1
Dk. Blue	(-1)-0

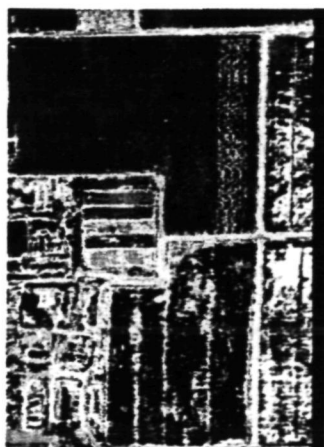


Figure 3. Pseudo-colored thermal imagery of the Phoenix test site acquired at 2:06 P.M., April 1, 1976.

	°C
Red	40-42
Orange	38-40
Violet	36-38
Grey	34-36
Yellow	32-34
Lt. Green	30-32
Aqua	28-30
Dk. Green	26-28
Md. Blue	24-26
Dk. Blue	22-24
White	20-22



Figure 4. Pseudo-colored imagery of the difference between P.M. and A.M. surface temperature measurements, April 1, 1976, Phoenix.

	°C
White	41-43
Red	38-40
Orange	35-37
Yellow	32-34
Lt. Green	29-31
Dk. Green	26-28
Lt. Blue	23-25
Dk. Blue	20-22
Violet	17-19
Black	14-16

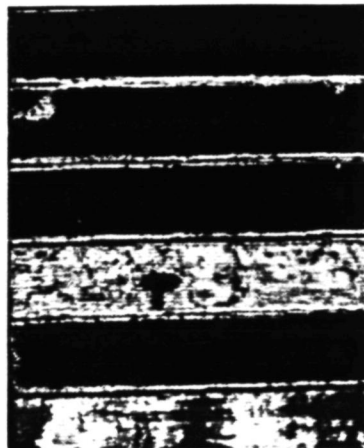


Figure 5. Pseudo-colored imagery of positive values of daily incremental stress degree days (afternoon crop minus air temperatures), April 1, 1976, Phoenix.

Red	8
Orange	7
Yellow	6
Lt. Green	5
Dk. Green	4
Lt. Blue	3
Dk. Blue	2
Violet	1
Black	0

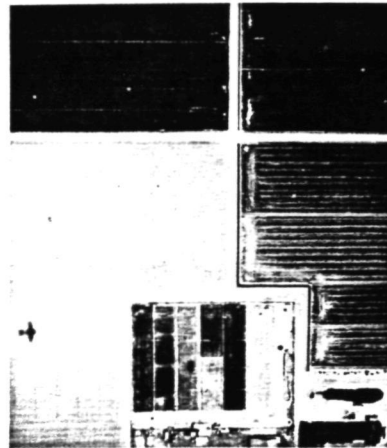


Figure 6. Color IR photograph of the Phoenix test site, April 29, 1976.

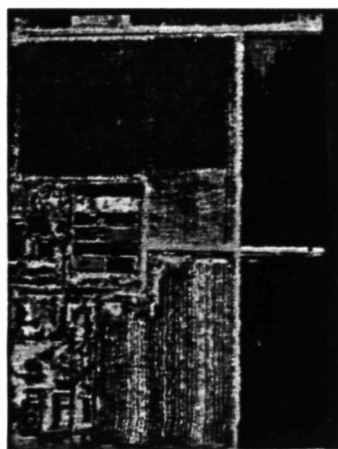


Figure 7. Pseudo-colored thermal imagery of the Phoenix test site acquired at 1:54 P.M., April 29, 1976.

Orange	50-53
Yellow	46-49
Lt. Green	42-45
Dk. Green	38-41
Lt. Blue	34-37
Dk. Blue	30-33
Black	26-29



Figure 8. Pseudo-colored imagery of positive values of daily incremental stress degree days (afternoon crop minus air temperatures), April 29, 1976, Phoenix.

Red	13-14
Orange	11-12
Yellow	9-10
Lt. Green	7-8
Lt. Blue	5-6
Dk. Blue	3-4
Violet	1-2
Black	0

DIGITAL COLOR ANALYSIS OF COLOR-RATIO COMPOSITE LANDSAT SCENES

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ABSTRACT

A method is presented that can be used to calculate approximate Munsell coordinates of the colors produced by making a color composite from three registered images. Applied to the Landsat MSS data of the Goldfield, Nevada, area, this method permits precise and quantitative definition of the limonitic areas originally observed in a Landsat color ratio composite. In addition, areas of transported limonite can be discriminated from the limonite in the hydrothermally altered areas of the Goldfield mining district. From the analysis, the numerical distinction between limonitic and non-limonitic ground is generally less than 3% using the Landsat bands and as much as 8% in ratios of Landsat MSS bands.

1. INTRODUCTION

In the past, discrimination of altered ground in mineral areas has been achieved using diazo color composites of Landsat ratio images (Rowan and others, 1974). Such discrimination relies on subjective recognition of particular colors in the color ratio composites and is strongly affected by variability in diazo film processing. A digital technique has been developed by which the digital ratios values can be numerically transformed from the three axes of an orthogonal coordinate system to a cylindrical coordinate system that approximates the Munsell color space (Strandberg, 1968). The colors that would result in a color-compositing process, such as the diazo process or a color additive process, thus can be precisely and quantitatively defined in terms of Munsell color coordinates.

This technique is illustrated by use of the color-ratio composite of the Goldfield, Nevada, area presented by Rowan and others (1974). The reader is assumed to be familiar with that report, and details of the compositing and geologic analysis are not repeated here.

2. METHOD

The geometric relationships involved in the transformations from an orthogonal coordinate system to cylindrical coordinate system approximating the Munsell coordinate system are shown in Figure 1. The Munsell coordinate system is a coordinate system that uses dimensions related to the psychological aspects of color (Strandberg, 1968). The three Munsell coordinates are hue, saturation, and value. Hue is basically the color such as red, green, brown, yellow, etc. Saturation is a measure of the purity, the higher the saturation the greater the purity for a given hue and value. The value is a measure of the brightness of the color, the greater the value, the brighter the color. With these three variables any color, as seen by a human observer, can be uniquely defined.

The equations used for the transform from the additive primary colors to Munsell coordinates are given in Table 1. The inverse equations, Munsell

coordinates to additive primary colors, are given in Table 2. These transforms assume a color-additive process with the additive primaries, blue, green, and red. The diazo process uses a color subtractive process. The relationship between color subtractive and color additive processes is shown in Table 3. If the relationships outlined in Table 3 are used, the same color composite will be derived with ideal color subtractive or color additive techniques. With the equations in Table 1, the colors that would be seen in the color-ratio compositing process can now be calculated. Briefly, the color-ratio-composite process as used by Rowan and others (1974) is as follows. The ratios of Landsat bands 4 divided by 5 (designated 4/5), 5 divided by 6 (designated 5/6), and 6 divided by 7 (designated 6/7) are formed. Then these ratios are linearly rescaled to the integers 0 to 255 which is the full range of gray levels of the film. Finally, positive black and white images on film (a high ratio has a low density on these images) are formed and these images are copied onto the appropriate color diazo film. The 4/5 image is cyan, the 5/6 image is yellow, and the 6/7 image is magenta. These color-coded ratios images are composited to form a color-ratio composite in which all colors are possible. The numerical analog using the equations in Table 1 and the relationships in Table 3 are as follows. The 4/5 ratio value is the red value, the 5/6 ratio value is the blue value, and the 6/7 ratio value is green. Then entering the calculated ratios into the transforms in Table 1, hue, saturation, and value are calculated. The blue, green, and red colors are centered at hue 0° , 120° , and 240° , respectively. The intermediate colors blue-green and yellow are centered at hues of 60° and 180° , respectively.

Now the reason that this precise transform gives an approximation of the Munsell coordinate system is apparent. The boundaries between these colors are not precisely defined. Therefore, a subjective decision has to be made with regard to what the individual interpreter considers the boundary. However, as a guide line, the divisions between the colors are approximately half-way between the pure hues. Furthermore, if in the color-composite image an observer recognizes the color as distinct, then the saturation must be high and the value moderate. Value can also be estimated by inspections of color composite images. Lack of definition of the colors in this numerical transform is not really a limitation, since any decision that is made is well defined, repeatable, and uniform for the whole data set. Thus, the decision can be exhaustively tested to see if it is acceptable and can be modified until an acceptable decision is derived.

As the transforms can be used both ways, additive primaries to Munsell and Munsell to additive primaries, a very powerful image enhancement technique is also available. Individual colors of a color composite image can be isolated or very subtle color variations can be enhanced for better visual interpretation of images. These operations can be performed by transforming from additive primaries to Munsell and then manipulating the desired color aspects. For example, the saturation may be increased for one set of hues that are critical to identify; thus making it easier to recognize those hues. Then the Munsell coordinates may be transformed back to the additive primary values and a new enhanced color composite image can be formed. A specific application of this concept will be discussed in the next section.

3. APPLICATION

Once a color-ratio composite is made with the diazo process, two basic problems are encountered. The first problem is that the recognition of colors is a subjective process and is greatly affected by surrounding colors. Associated with this problem is the fact that the diazo process is not exactly repeatable. The second problem is that by using the diazo process, digital ratios produced in a well controlled numerical process have been transformed into a less-well controlled analog product. Thus, questions concerning the numerical aspects such as what are the ratios that produce green on the color-ratio composite are very difficult to answer. The advantage of the color-ratio-composite process is that the human mind can be applied to interpret an image so that image factors such as texture, shape, and association can be taken advantage of. Therefore, more than just the spectral aspects of the problem can contribute to the analysis. Thus, the method presented in the previous section is not really a substitute for the color-ratio-compositing process but

is another tool to further the analysis of the color-ratio-composites. In the rest of this paper I will present examples of the application of this method to the two problems mentioned above.

The first problem is recognition of a specific color. For the color-ratio-composite image of the Goldfield, Nevada area, Rowan and others (1974) state that there is excellent coincidence between the limonitic areas such as the Goldfield mining district and the green color seen in the image. However, upon detailed inspection of these areas, I have found that it is not a straightforward matter to outline and map these green areas. Conversion to Munsell coordinates is a method to do this mapping of green areas in a well defined and repeatable fashion.

Figures 2 through 5 show images that were formed in producing the map in Figure 6 of the green areas of the color-ratio-composite images, that is the limonitic areas. These figures all cover the same area discussed by Rowan and others (1974). Figure 2 shows in black those pixels with the hues 87 to 132, the green hues. These exact numbers are image dependent. At first inspection there appear to be too many, but detailed inspection of the color-ratio-composite image shows there are indeed green pixels in all of these areas. However, there are differences in distribution of the green pixels. In the Goldfield area, the green pixels are concentrated whereas on the pediments the green pixels are scattered. This distribution is consistent with differences expected in limonite occurrence, comparing an area containing abundant iron sulfides and oxide minerals due to intense hydrothermal alteration and an area of minor scattered iron staining on a colluvium-covered pediment. The exact hue interval was selected by inspection so as to include all areas selected by Rowan and others (1974).

To further refine Figure 2, the saturation was considered next. On inspection of the Goldfield color-ratio-composite image, the greens are seen to be very distinct, easily recognized greens. Therefore, the greens of interest have a high saturation. Figure 3 shows in black those pixels with the green hues selected in Figure 2 that have a high saturation. The number of pixels selected has been greatly reduced and most of the areas of concentrated pixels are the limonitic altered areas selected by Rowan and others (1974).

Now the problem of noise in the Landsat data and the problem of individual isolated pixels is apparent in Figure 3. There is a conspicuous six-line stripping in this figure that is related to the miscalibration of the six detectors on the Landsat multispectral scanner. One solution is to filter every sixth line to subdue this stripping. Figure 4 shows the result. The second problem--isolated pixels--is only a problem in the sense that I am not interested in a limonitic area of only one isolated pixel. Figure 5 is the result of removing all selected pixels from Figure 4 that have no immediately adjacent neighbors.

Finally, color coding Figure 5 and registering this image onto an image of Landsat band 5, a map (Figure 6) is produced showing in red those pixels that were green and relatively concentrated in the color-ratio-composite image. Specifically, this is a map of those pixels with high saturation and green hues after corrected for a sixth-line stripping and removal of isolated pixels. The limonitic areas selected by Rowan and others (1974, figure 18) are seen as concentrations of red.

Now that the green pixels have been located and defined numerically, the question of what numbers in the three ratios combined to produce green in the diazo composite, can be answered. Table 4 presents the statistics of the Landsat bands and ratios of various colors or areas of interest that were defined by the process discussed above. These precise numbers are of course dependent upon the atmospheric conditions and the calibration of the satellite at the time the data were acquired. However, from work in other areas it appears that these numbers are approximately the same from area to area.

From inspection of Table 4 a further application of this methodology is suggested. There is a very small numerical difference between the green areas

of the Goldfield mining district and the green areas on the pediments. Can this difference be seen in an image? Figure 7 shows an approach to this question. Figure 7a is band 5 of the area around the Goldfield district and extends south to the Cuprite district. Figure 7b is an attempt to take advantage of this very small difference between the greens at Goldfield and on the pediments. It involves the following steps: (1) transform the ratios to Munsell coordinates, (2) in the hue dimension, linearly translate the green, yellow, and brown hues to occupy all possible hues and make all other hues zero, (3) increase the contrast in the saturation and value dimensions, and (4) transform these enhanced Munsell coordinates back to additive primary colors, ratios in this case, and form an enhanced color-ratio composite. Figure 7b shows the variation of the green, yellow, and browns of the original color-ratio-composite image as variation of all hues except blue, a hue of zero. The limonitic areas at Goldfield and Cuprite are both distinct. The non-limonitic area at Cuprite is also anomalous. Furthermore, as hoped, the areas of transported limonite on the fans are partially distinct from the limonitic areas at Goldfield and Cuprite. A possible explanation of why these differences are seen does not require the transported limonite on the pediments to have different spectral properties than the limonite at Goldfield. This difference could be simply related to the distribution or concentration of limonite within the 80 meter resolution cell of Landsat, a mixture problem.

4. CONCLUSION

The application of the equations in Tables 1 and 2 has allowed a significant improvement in the analysis and understanding of color-ratio-composite images. This method provides a numerical method that is analogous to the color compositing procedure and complements that procedure. The information derived from this analysis is suggesting many further avenues of research. However, the application of this technique is not limited to analysis of color-ratio composites; it could be applied to the analysis of any color image.

5. ACKNOWLEDGMENT

I would like to acknowledge the help of Don L. Sawatzky in deriving the equations used in this analysis.

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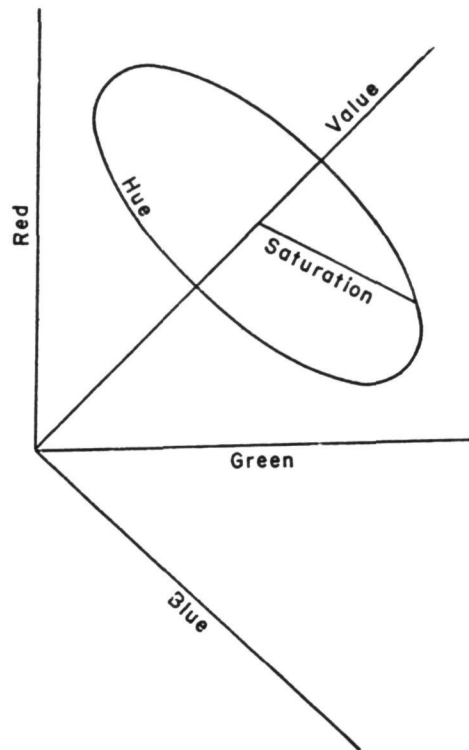


FIGURE 1: GEOMETRIC RELATIONSHIP BETWEEN THE ORTHOGONAL COORDINATE SYSTEM OF THE ADDITIVE PRIMARY COLORS AND THE CYLINDRICAL COORDINATE SYSTEM THAT APPROXIMATES THE MUNSELL SYSTEM. The cylindrical system is oriented such that the angle between the value axis and all additive-primary-color axes is the same. The saturation axis is normal to the value axis, and the hue is the azimuth of the saturation axis measured in a plane normal to the value axis. In the cylindrical coordinate system the azimuth of the blue axis is arbitrarily taken as the zero azimuth; thus, the green axis has a hue of 120 and the red axis has a hue of 240.

FIGURE 2: THIS IMAGE SHOWS IN BLACK THOSE PIXELS THAT HAVE GREEN HUES. This image, and Figures 3 through 5, was formed so that adjacent pixels would overlap on exposure; thus increasing the print density where there are adjacent selected green pixels. This was done to emphasize areas of concentrations of pixels such as the Goldfield mining district.

FIGURE 3: THIS IMAGE SHOWS ONLY THOSE PIXELS IN FIGURE 2 THAT HAVE HIGH SATURATION.

FIGURE 4: THIS IMAGE IS THE RESULT OF MAKING A CORRECTION FOR THE SIX-LINE STRIPPING OF FIGURE 3.

FIGURE 5: THIS IMAGE IS THE RESULT OF REMOVING ISOLATED PIXELS FROM FIGURE 4.

FIGURE 6: THIS IMAGE IS FIGURE 5 CODED IN MAGENTA AND REGISTERED ON LANDSAT BAND 5. The red areas are areas where there are concentrations of limonite at the surface. This image numerically reproduces in red the green areas in Rowan and others (1974, figure 18).

FIGURE 7a: LANDSAT BAND 5 OF THE GOLDFIELD MINING DISTRICT. This is the same area as in Figure 7b.

FIGURE 7b: AN ENHANCED VERSION OF THE COLOR RATIO COMPOSITE SHOWING THE VARIATIONS OF GREEN, YELLOW, AND BROWN OF THE ORIGINAL AS ALL COLORS EXCEPT BLUE. Notice that the transported limonite southeast of Goldfield is distinct from Goldfield.

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FIGURE 2



FIGURE 3



FIGURE 4



FIGURE 5

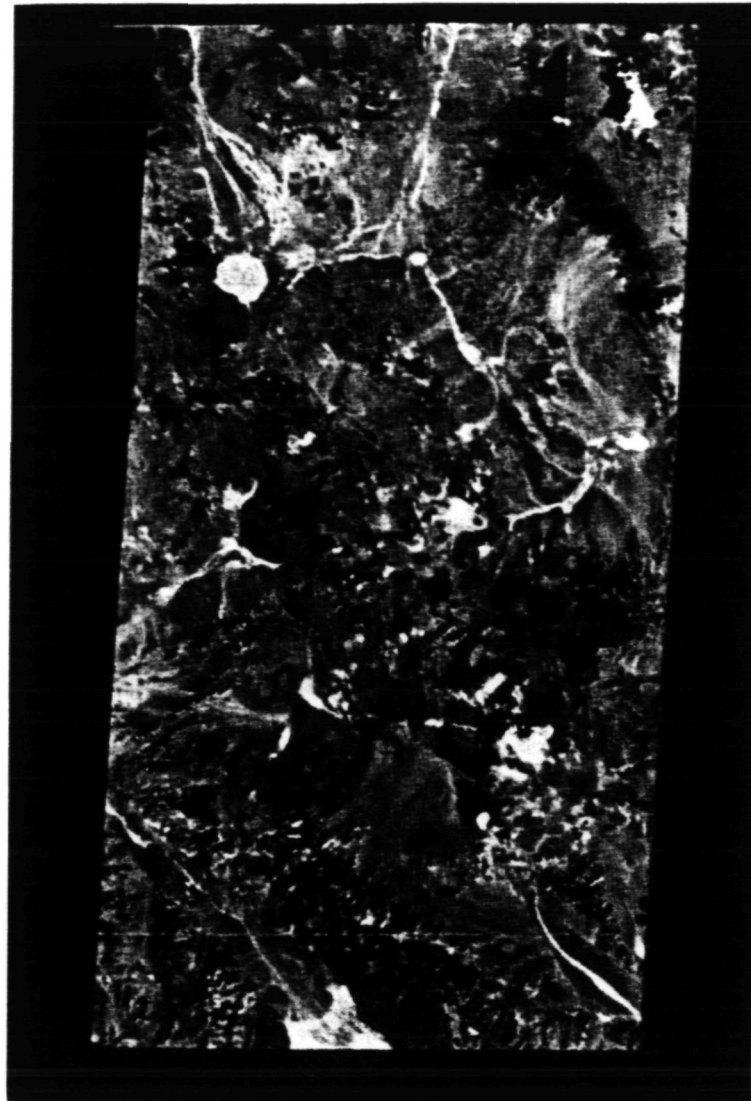


Figure 6

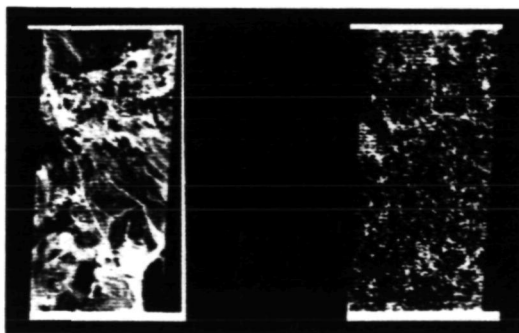


Figure 7a

Figure 7b

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Table I: Transformation of the Additive Primary Colors to Munsell Coordinates.
In the example being considered, the blue ratio value is from the 5/6 ratio (Landsat band 5 divided by 6), the green ratio value is from the 6/7 ratio, and the red ratio value is from the 4/5 ratio.

B = blue ratio value
G = green ratio value
R = red ratio value

$$K2 = \frac{\sqrt{2}}{2}, \quad K3 = \frac{\sqrt{3}}{3}, \quad K6 = \frac{\sqrt{6}}{6}, \quad K7 = \frac{\sqrt{6}}{3}$$

$$B1 = (K7 \times B) - (K6 \times R) - (K6 \times G)$$

$$X1 = (K2 \times G) - (K2 \times R)$$

if $B1 = 0$, Hue = neutral, i.e., $B = G = R$

$$B1 \neq 0, \text{ Hue} = \arctan \frac{X1}{B1}$$

$$\text{Saturation} = (B1^2 + X1^2)^{\frac{1}{2}}$$

$$\text{Value} = K3 \times (B + G + R)$$

Table II: Transformation of the Munsell Coordinates to Additive Primary Colors.
The constants are the same as Table I.

H = hue
S = saturation
V = value

$$B1 = S \times \cos(H)$$

$$X1 = V \times \sin(H)$$

$$\text{Blue} = (K7 \times B1) + (K3 \times V)$$

$$\text{Green} = (K2 \times X1) + (K3 \times V) - (K6 \times B1)$$

$$\text{Red} = (K3 \times V) - (K2 \times X1) - (K6 \times B1)$$

Table III. Relationship Between Images Used in Color-subtractive and Color-additive Processes.
In order to obtain the same color-composite image, the equivalent images and primary colors are as listed below.

Color Subtractive		Color Additive	
Image	Primary Colors	Primary Colors	Image
Positive, large value is bright	Cyan	Red	Negative, large value is dark
	Yellow	Blue	
	Magenta	Green	

Table IV: Mean Values and Typical Standard Deviations for Selected Colors of Interest.

The pixels in bands 4, 5, and 6 were multiplied by 2 to put the data in the 0 to 255 range, and the pixels in band 7 were multiplied by 4 to get them in the 0 to 255 range. The average ratios were calculated by recalculating the ratios from the bands, not by ratios of the average values of the band. Only typical standard deviations are given because there was very little variation between bands and ratio.

	Whole Scene	Mud Lake	Vegetation (red)	Goldfield (green)	Limonite Pediment (green)	Brown Areas
Sample Size	236,334	5,000	10,000	6,791	3,010	1,748
Band 4	83.2	183.3	47.3	85.1	89.2	87.7
Band 5	90.1	202.4	42.4	93.8	98.8	99.1
Band 6	83.0	175.9	51.9	85.7	90.4	94.9
Band 7	70.7	139.8	53.1	70.4	76.0	83.2
Typical standard deviation for bands	33	15	12	12	10	17
4/5 ratio	0.981	0.907	1.163	0.914	0.906	0.891
5/6 ratio	1.091	1.151	0.813	1.098	1.093	1.047
6/7 ratio	1.178	1.259	0.985	1.218	1.191	1.143
Typical standard deviation for bands	1.00	0.04	0.13	0.06	0.05	0.06

LANDSAT DATA FROM AGRICULTURAL SITES:
CROP SIGNATURE ANALYSIS*

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ABSTRACT

The LANDSAT multispectral scanner (MSS) data have been analyzed with a view toward classification to identify wheat. The notion of spectral signature of a crop, a commonly used basis for classification, has been found to be inadequate. Data analysis has revealed that the MSS data from agricultural sites are essentially two dimensional, and that the data from different sites and different acquisitions lie on parallel planes in the four-dimensional feature space. These results have been exploited to gain new insight into the data and to develop alternate models for classification. In particular, it has been found that the temporal pattern of change in the spectral response of a crop constitutes its signature and provides a basis for crop classification.

1. INTRODUCTION

The classification of multispectral observations from agricultural sites is commonly based on the notion of spectral similarity of like ground covers in a scene. With this model, the data are characterized on the basis of a sample of training fields from each crop class of interest. The data from each class are usually assumed to be Gaussian, and, then, the characterization consists of computation of sample mean and dispersion matrix. These parameters are said to constitute the 'spectral signature' of the class and are used as a basis for classification of the test data [1-3].

Experience with LANDSAT multispectral scanner (MSS) data, however, has shown this model generally to be inadequate for crop classification. While the within-field variability of data is small, the field-to-field variability is usually so large as to make the notion of representative fields of a crop class untenable. This difficulty is compounded by the lack of wide separability in the data from different crop classes. Both these factors depend upon the relative biological phases of the different crops in the scene at the time of the data acquisition. In wheat identification problem, for example, it has been found that in most instances the data from any single acquisition at any time during the wheat crop calendar cannot be classified satisfactorily on the basis of the spectral similarity model. Actually, even with multitemporal data (i.e. merged data from multiple acquisitions at different times in the crop calendar of wheat), the different sets of training fields produce substantially different classification results [4].

The difficulty with basing classification on spectral signatures described above is illustrated in Figures 1a and 1b. These figures provide typical plots of the mean vectors for several randomly selected wheat and nonwheat fields in a LANDSAT subframe covering a 5x6 nautical miles area in Kansas. The plots correspond to four acquisitions over the site during different biological phases (viz., crop establishment, green, heading, and mature) of the wheat crop. The sizes of the fields range from 50-100 ground resolution elements (pixels). The standard deviations in the four channels range from 0.9 to 3.5. Figure 1a suggests that the data from the wheat fields cannot reasonably be modeled as having been drawn from the same probability distribution. Actually, hypothesis tests for equality of mean vectors across wheat fields invariably fail at each stage of the crop. In a generalization of the model described

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above, the data from each crop class are regarded to constitute a Gaussian mixture distribution [5]. This model, though more realistic, is still not entirely adequate for a situation where training is based on data from sample of fields. Quite often the mixture distribution is found to have as many constituents as there are fields! The basic difficulty, of course, still is with the notion of distinct spectral crop classes and their representation in a sample of training fields.

With this background, an extensive analysis of the LANDSAT MSS data was undertaken with the objective of discovering features of spectral response that constitute a signature of wheat. The data available for this study consisted of mean vectors and dispersion matrices for a number of known wheat and non-wheat fields from each of several sites with multiple acquisitions. The results of data analysis are given in the next section.

2. SIGNATURE ANALYSIS

The following findings on the LANDSAT MSS data from agricultural sites were reported by the authors in an earlier paper [6]. (1) The data from any acquisition are essentially two dimensional, and (2) the data from different acquisitions/sites essentially lie on parallel two-dimensional planes in the four-dimensional feature space. See also the related, independent work of Kauth and Thomas[7], who give an interesting phenomenological identification to the spectral measurements and report roughly similar conclusions on the dimensionality of the data.

The above finding on dimensionality offers a significant benefit in terms of graphical display of the four-dimensional data. This can be done by finding representation of the data in a rotated coordinate frame with, say, the first two axes on the plane of the data and the remaining two orthogonal to it. In this representation, the first two (in-plane) components, giving the location of the data on the plane, essentially distill the 'information' from the four-channel MSS data; the last two (off-plane) components, measuring the deviation of the data from the plane, have only a very small range of values and are regarded as noise. The relative positions of the data in the original four dimensional feature space are very nearly preserved in a data display based only on the first two components of the transformed data. Note that having identified the plane, for our purpose, the orientation of the two orthogonal axes on it is entirely arbitrary [6]. The coordinate frame, i.e., orthonormal transformation (see Appendix), used in the graphical representation of data in this paper was chosen solely for clean displays. In plots of in-plane (off-plane) components, the first (third) component of the transformed data is plotted along the abscissa.

Figures 2a and 2b give scatter plots of data from the Kansas site (acquisition 2) mentioned earlier. These data correspond to 22,932 ground resolution elements in the scene. The plots use characters .,1,2,...,9,A,B,..., Z to represent 36 increasing levels of concentrations in a cell. The character assignment is on a uniform scale in the range 1 through KMAX, specified on the plots. The plot in Figure 2a is typical; the data are densely packed in a roughly triangular region with no apparent cluster structure. The spectral similarity model, however, is predicated on the existence of cluster structure in the data. The scatter plot of the off-plane components is also typical; it demonstrates the two-dimensionality of the data.

For each of the available acquisitions over several sites, the transformed mean vectors of a set of wheat and nonwheat fields were plotted on the plane of the data. Two such scatter plots are presented in Figures 3a and 4a. The former corresponds to a site in Kansas with registered data available from six acquisitions over the crop calendar of wheat. Figure 4a corresponds to a site in Oklahoma with eight acquisitions. The acquisition dates are given below each plot as five-digit numbers. The first two digits identify the year, and the last three the day of that year. These two sites were chosen for availability of good-quality data from several acquisitions over each. In view of the small within-field variability, the data from all pixels of a field can be

thought of as densely scattered about the mean. The wheat grown at both sites is of winter wheat variety. It is planted early in the fall, is dormant during winter, greens and matures during spring, and is harvested in early summer.

Figures 3a and 4a illustrate the difficulty with the spectral signature model for wheat identification. The large field-to-field variability, as noted earlier, is generally compounded by the lack of strong separability in wheat-nonwheat data. For example, in Figure 4a, in one-half of the acquisitions the decision boundaries are not apparent to separate the wheat and nonwheat data from the training fields. Even in cases where such decision boundaries can be drawn, what can be said of classification of the test data?

Experience with maximum likelihood classification with Gaussian (-mixture) model for data from the various crop classes has shown that the decision boundaries determined by the different sets of training fields are substantially different. The more training fields there are of wheat, the greater is the amount of wheat discovered in the scene by classification of data [4]. The reason for this is apparent from Figures 3a and 4a. The difficulty is that the data from a sample of fields of a crop class is not representative of the population. A better characterization of the data would be obtained by taking a pixel, rather than a field, as a unit for training. For example, a 5% sample of pixels from the wheat fields in a scene would provide a better basis for characterization of the distribution of the wheat data than a set of pixels of the same size belonging to a sample of wheat fields. Such training process, however, is not deemed cost effective in large-scale utilization of the LANDSAT data.

This basic difficulty in characterization of the data from different crop classes is resolved by examining the pattern of temporal changes in the spectral response. Again, the results on the data dimensionality have been crucial to this work: The temporal pattern can be plotted as a trajectory on the plane of the data by joining together the points representing the locations of the field means in successive acquisitions. Figures 3b, 3c, 4b, and 4c present these temporal trajectories for some of the training fields from the Kansas and Oklahoma sites. An asterisk marks the starting point of each trajectory. The scale of each plot, unless otherwise specified, is the same as that of the plot above it.

These trajectories constitute a complete graphical description of the spectral-temporal response of the field. Note that for each of the two sites, the trajectories associated with wheat fields are similar, and are sufficiently distinct from the corresponding trajectories of nonwheat. Even for acquisitions where the wheat and nonwheat data had appeared confused, the corresponding patterns of spectral changes bear unique information for classification. Examination of multitemporal data from a number of sites has revealed that in each case the pattern of temporal changes characterizes the crop and constitutes a valid signature. Supervised classification of the data can be based on features extracted from the temporal trajectories of the training fields [8].

Simple interpretations based on crop phenology can be associated with this pattern. It has been proposed, [7], for example, that in our coordinate frame on the plane of the data, the abscissa and ordinate give measures of brightness and greenness, respectively, of the ground cover. Interpretation of the temporal trajectories of winter wheat in terms of the anticipated phenomenological changes generally supports this view, though this issue appears far from resolved.

Note that the trajectories associated with wheat fields at the two sites have certain qualitative similarity. Both sets are sampled versions of a continuous trajectory which appears to resemble an ℓ (lower case script E). The sampling times at the Oklahoma site (Figure 4b), however, are such as to miss the distinguishing feature of the 'loop'. Distortion in trajectories can be introduced by atmospheric conditions, such as haze. The nature of this distortion, however, being common to data from all classes, would generally not mask the class-specific features. Such identification of the features of the

temporal trajectory with the crop phenology and the atmospheric conditions would permit development of unsupervised crop-calendar tracking classification schemes.

3. CONCLUSIONS

Graphical representation of the LANDSAT MSS data acquired during the different phases of the wheat crop has shown that wheat can be identified on the basis of its characteristic pattern of temporal changes in the spectral response. This pattern can be interpreted in terms of the crop calendar and the crop vigor. Features of this temporal pattern provide a basis for both supervised and unsupervised classification of the data. These results, presented here in the context of wheat identification, are applicable to the general crop classification problem.

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APPENDIX

Orthonormal Transformation for the MSS Data

The following orthonormal transformation was used for the graphical representation of data in Figures 2-4.

$$T = \begin{bmatrix} 0.406 & 0.600 & 0.645 & 0.243 \\ -0.386 & -0.530 & 0.535 & 0.532 \\ 0.723 & -0.597 & 0.206 & -0.278 \\ 0.404 & -0.039 & -0.505 & 0.762 \end{bmatrix}$$

The rows of T define the bases vectors of the new coordinate frame. The first two rows span a subspace parallel to the plane of the data.

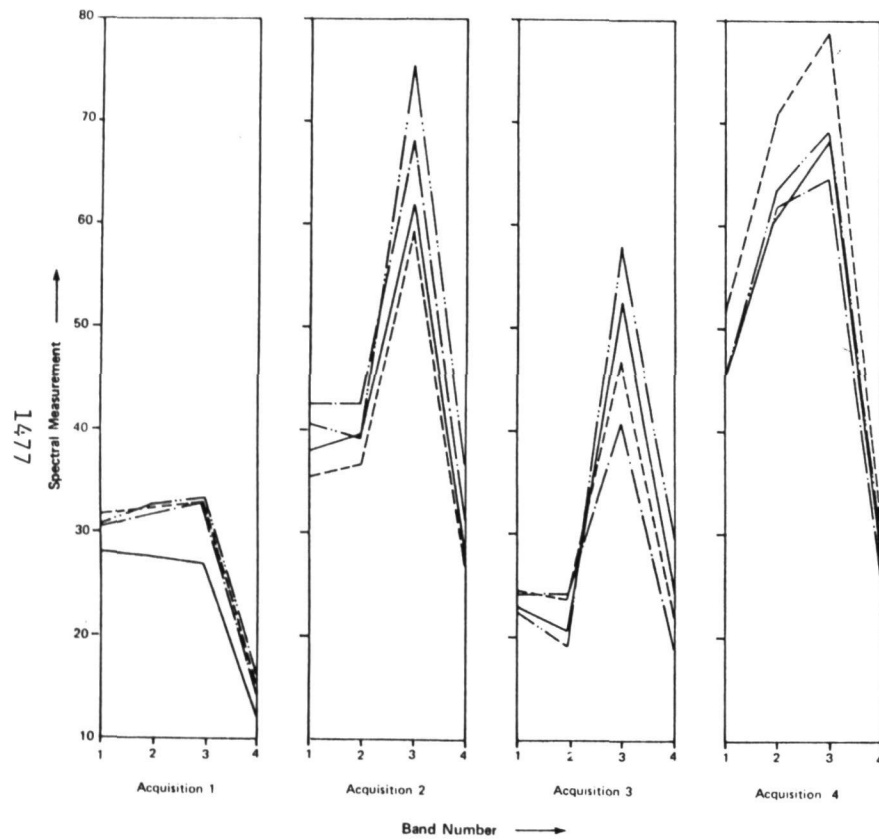


Figure 1a. Plots of Mean Vectors for Four Wheat Fields

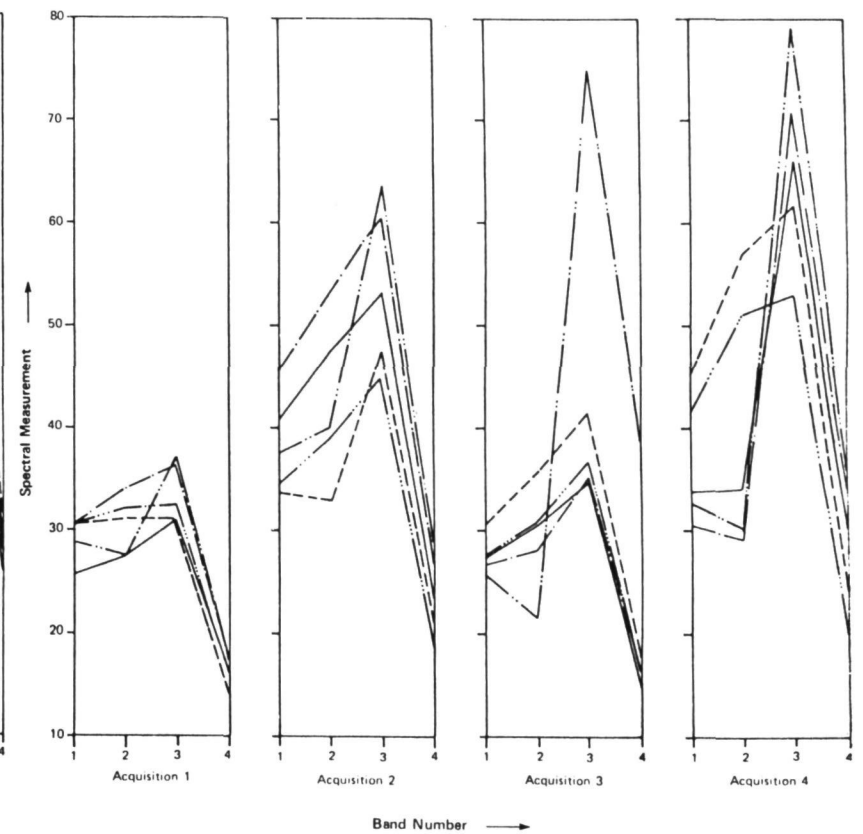


Figure 1b. Plots of Mean Vectors for Five Nonwheat Fields

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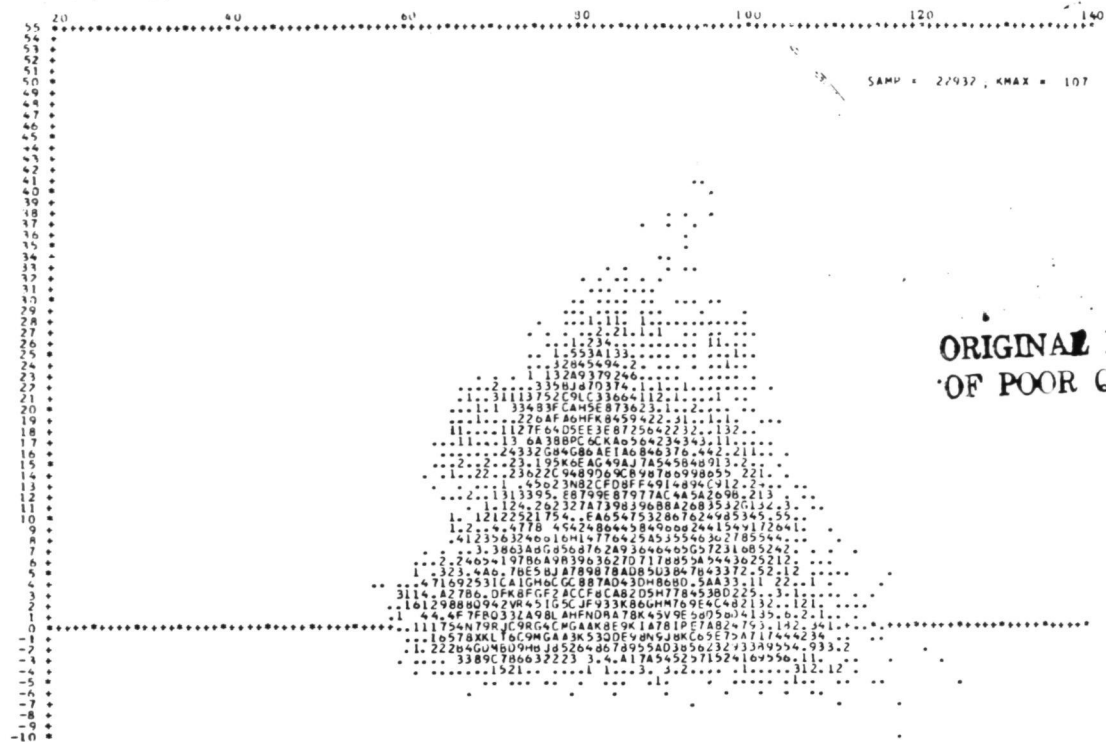


Figure 2a. Scatter Plot of the In-plane Components of Data

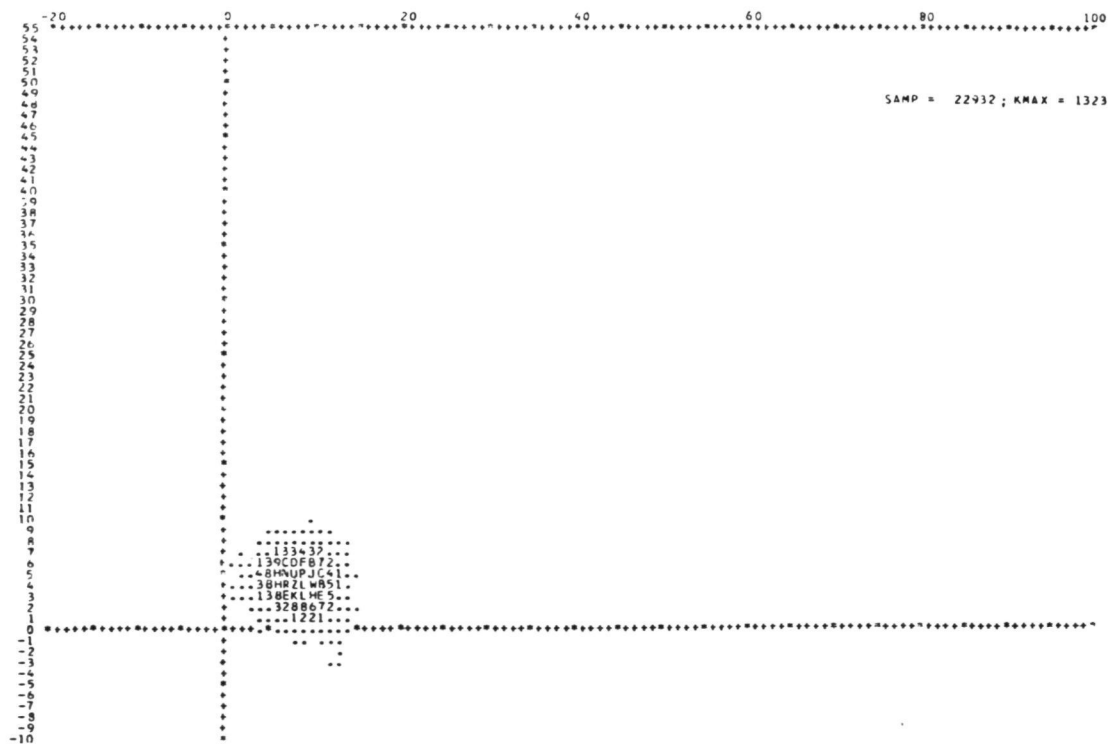
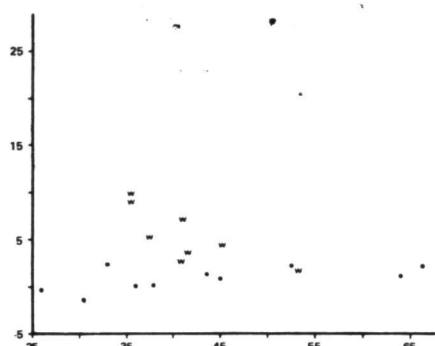
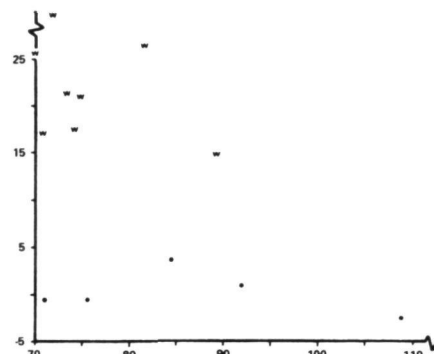


Figure 2b. Scatter Plot of the Off-plane Components of Data

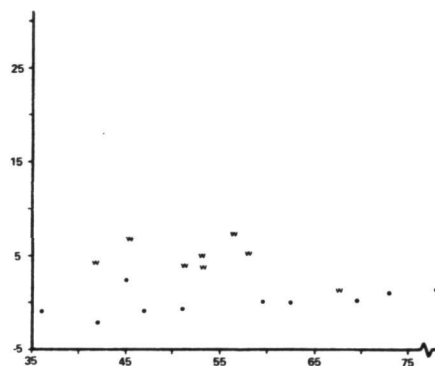
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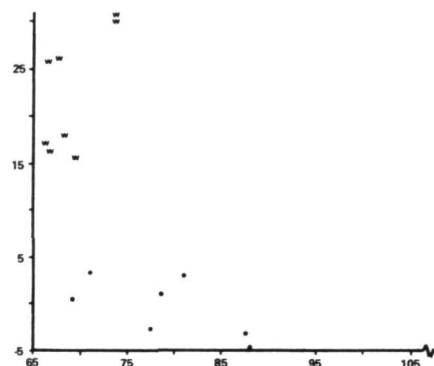
Acquisition 1: 75349



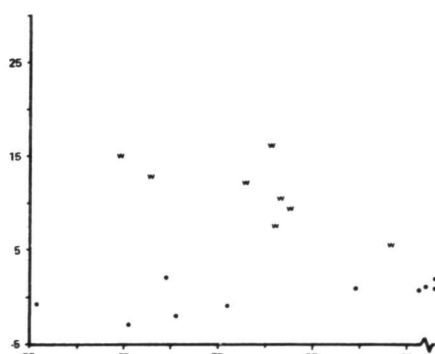
Acquisition 4: 76109



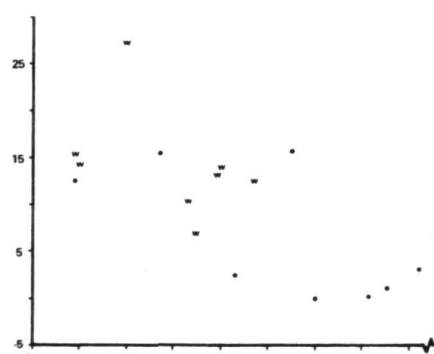
Acquisition 2: 76038



Acquisition 5: 76127



Acquisition 3: 76073



Acquisition 6: 76164

Figure 3A. Scatter Plot Of Field Means (Kansas)

w - Wheat; • - Nonwheat

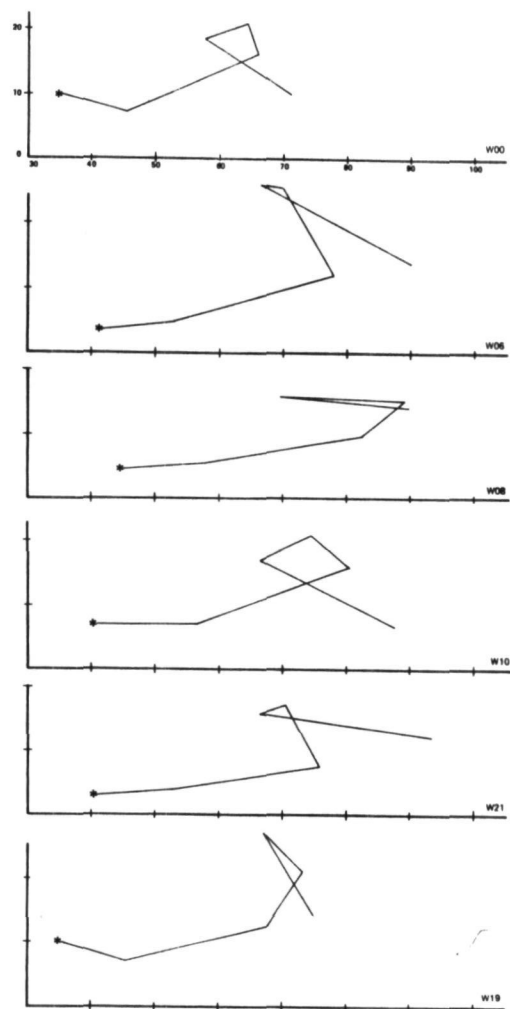


Figure 3B. Temporal Trajectories Of Wheat Fields

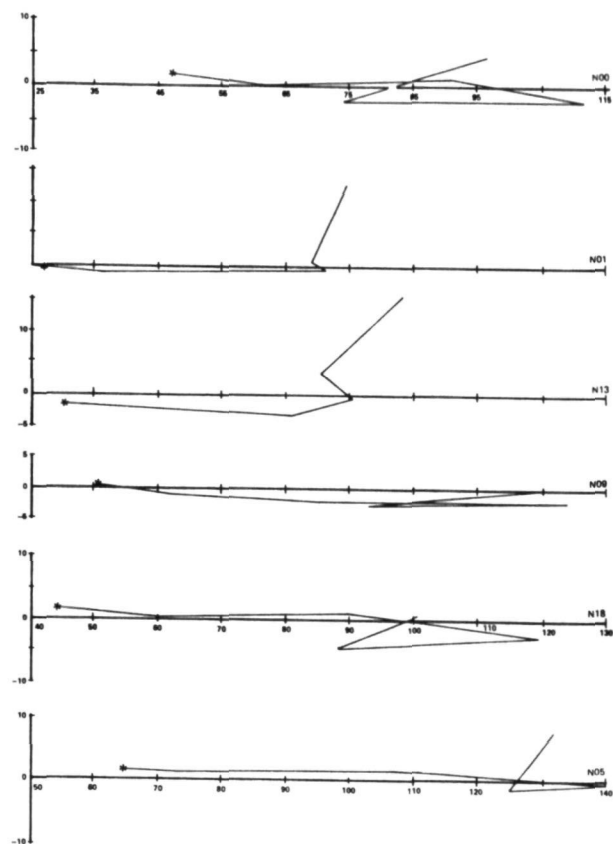


Figure 3C. Temporal Trajectories Of Non Wheat Fields

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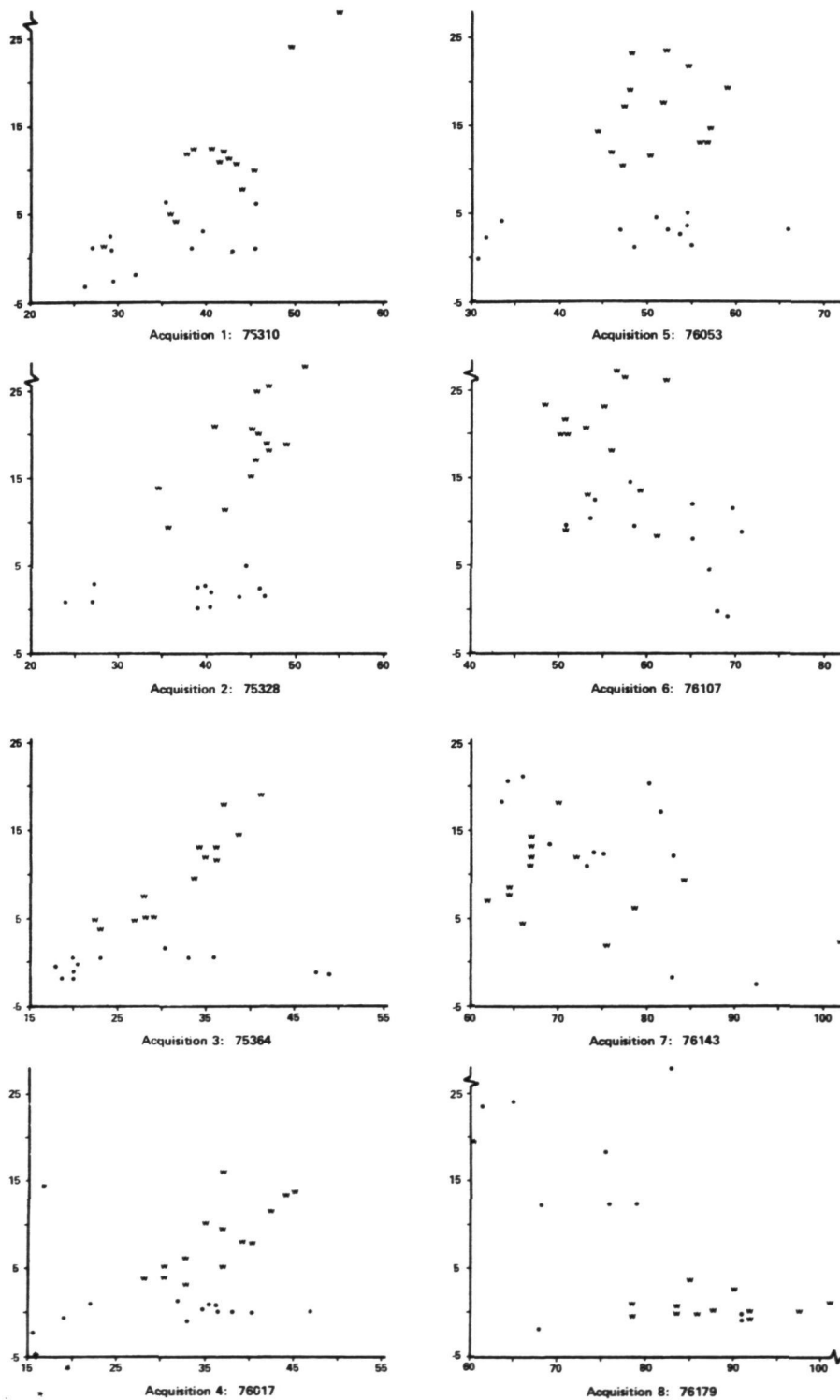


Figure 4A. Scatter Plot Of Field Means (Oklahoma)

w - Wheat; • - Nonwheat

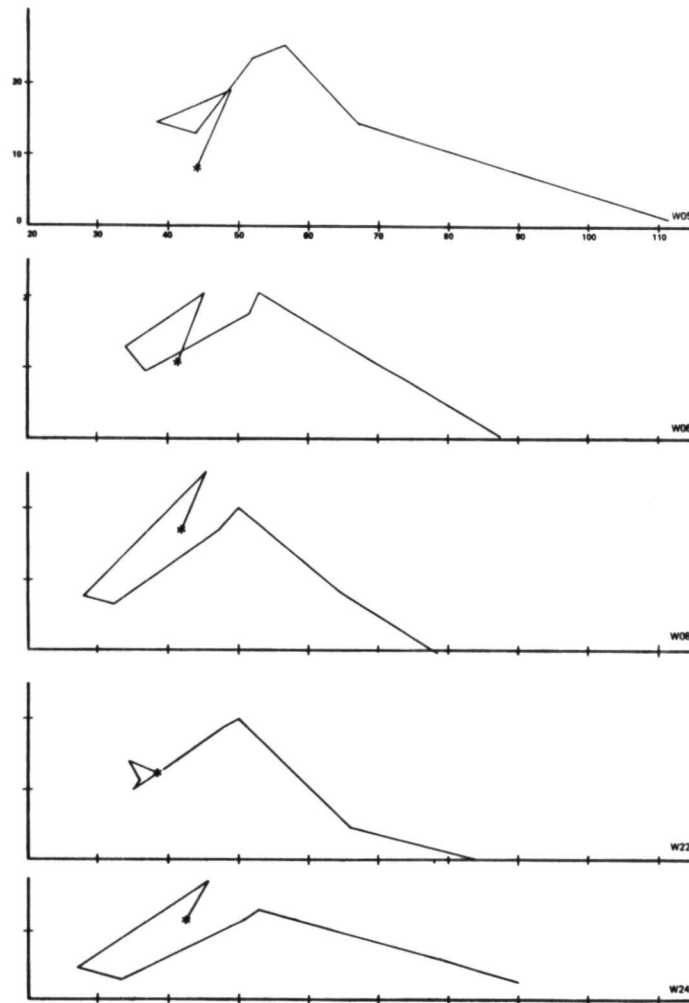


Figure 4B. Temporal Trajectories Of Wheat Fields

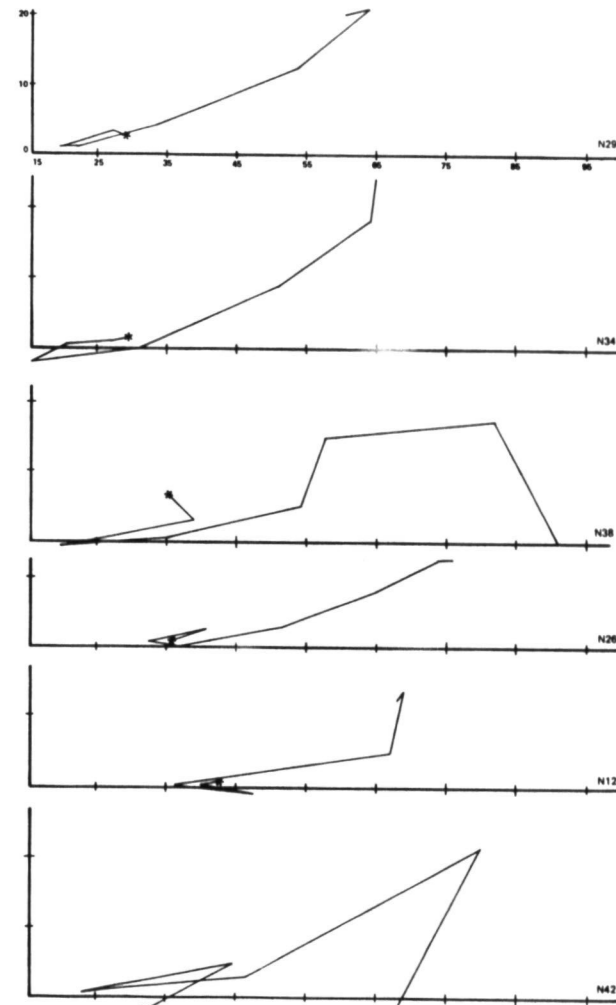


Figure 4C. Temporal Trajectories Of Non-Wheat Fields

INVENTORY OF RICEFIELDS IN FRANCE USING LANDSAT AND AIRCRAFT DATA

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ABSTRACT

The methodology for mapping ricefields in Southern France is developed, using 1975 LANDSAT 2 and aircraft data and taking into account the features of the fields.

As part of the LANDSAT 2 programme on Agricultural Resources Investigations in Northern Italy and Southern France (the AGRESTE programme) (1), research has been carried out in the Camargue French test-site on rice crop in order to make an inventory of the total area of rice cultivation within the test-site.

The study is performed at several levels : ground observations, aircraft and satellite imagery, after consideration of the features of French ricefields.

1. DESCRIPTION OF RICEFIELDS IN SOUTHERN FRANCE

The arrangement of ricefields in Southern France depends on the ecological and agricultural conditions of the zone. Areas of rice cultivation consist of adjacent parcels, the size of which depends mainly on the local topography. The parcels are leveled so that water depth can be controlled to within one centimeter. This implies that the parcels be narrow and that they follow contour lines.

Given this restriction, most of the ricefields are divided into small parcels (40 m, 50 m wide and 100 to 400 m long). The parcels are separated by 4 to 10 m wide dirt roads which must permit transportation operations (sowing, chemical treatment, harvest..) which often take place after the fields have been flooded. After flooding, the fields look like a mosaic of rectangular surfaces with the water level at about 10 cm.

Furthermore, several varieties are cultivated : Balilla, Euribe, Delta Cristal, Cigalon, Arlésienne, RB... and this effects the irrigation conditions which depend partly on the water requirements of the plants. The cover rate during the vegetative stage can vary also from parcel to parcel depending on the variety planted.

In addition, identification of ricefields by their spectral properties may be difficult : confusion with natural water bodies at the sowing stage and with marshes at the vegetative stage is possible.

2. GROUND DATA DETERMINATION

Data were collected simultaneously with the passages of Landsat 2 for the vegetation season of 1975.

The stages of development of rice are determined for the 3 most commonly cultivated rice varieties in the Camargue region, i.e. the Delta, Euribe, and Balilla 28 varieties. Table 1 summarizes the soil conditions and the growth stages observed during the passages of Landsat 2. The growth stages are defined

according to international standard (2).

At the same time climatic measurements were recorded in an experimental ricefield giving air temperature, wind (direction, speed) soil temperature, sun, relative air moisture and rainfall recordings (3).

In conjunction with ground observations and measurements, Landsat 2 data processing plan can be outlined (table 2).

3. STUDY OF THE AERIAL IMAGERY

During a B 17 flight over the test site at 7000 m and 1500 m, June 20, 1971, IRC and IR black and white images, as well as Daedalus Scanner recordings were obtained.

Photointerpretation of 7000 m IRC images provides the location of several samples of ricefields and other field categories in the area : vineyards, wheatfields, marshes and urban areas. On June 20, the ricefields are under water and different varieties exhibit different growth stages : from emergence to beginning of tillering. On IRC images ricefields appear as blocks of mixed blue and pink tone.

Daedalus images, especially those from the 2 channels closest to the MSS 5 and MSS 7 bands of LANDSAT : channel 7 : 650 - 700 nm, channel 10 : 900 - 1100 nm are studied. On channel 7, the interpretation presents some ambiguity between ricefields and wheatfields while in channel 10, ricefields are confused with temporarily flooded plots (vineyards, market gardens).

In conjunction with photointerpretation and knowledge of the topography, the pedological and hydrological considerations of the zone, the test site which includes the totality of ricecultivation in France is divided into 4 rectangular areas or strates, suitable for computer aided classification.

Figure 1 shows the test site (43° 24' to 43° 45' North, 4° 25' to 4° 50' East) divided into 4 subsets :

1. Arles Area : 20 km x 20 km
2. Aigues Mortes : 20 km x 11 km
3. Ste-Marie de la Mer : 11 km x 11 km
4. Port St-Louis : 15 km x 20 km

4. METHODOLOGY FOR DATA PROCESSING

On the 8 LANDSAT images expected, 4 were available : July 6 (2165 - 09511), July 23 (2182 - 09451), August 11 (2201 - 09502), October 3 (2254 - 09440). Landsat and aircraft data are processed first for the study of ricefield response. Then Landsat data are processed for ricefield classification.

4.1. STUDY OF RICEFIELD RESPONSES

Photo-interpretation of aerial images serves as a guide to the study of the homogeneity of ricefields responses.

An area is defined as homogeneous when the gradient at all points is zero or less than a threshold determined by the measurement noise. In addition to this concept of instrumental homogeneity, there is also the concept of the homogeneity of the ground object. The latter is related to the resolution problem. With Landsat resolution, such agricultural terrain as vineyards or orchards with a structure of alternating vine and soil or trees and soil appear as stable composites and the samples taken within these types of terrain have homogeneous responses.

4.1.1. FROM AERIAL IMAGES : to study the homogeneity of ricefields, 1500 m IR black and white images are digitized by means of the Joyce-Loebl Scandig microdensitometer, delivering an 8 bit coded optical density for every pixel of about 2 m x 2 m.

Figure 2 shows a part of an original image including ricefields, wheafields and meadows. Several samples of each field category are located and studied by means of their histogram. As expected, the histogram of ricefield samples exhibits larger dispersion than other fields. Table 3 shows some statistics computed on ricefield, wheatfield and meadow samples, each of which corresponds to an area of 40 pixels x 30 pixels (80 m x 60 m). The case of Landsat pixel can be then simulated by taking the mean value of each sample. The non uniformity of ricefield responses is then demonstrated by the wide range of mean values of ricefield samples in table 3.

4.1.2. FROM LANDSAT IMAGES : Several samples are extracted from Landsat 2 images of July 6, July 23 and August 11 : cereals, vineyards, meadows, ricefields. Figure 3 shows the Landsat 2 image enlargement of the test site (on July 23, 75) and table 4 compares statistics computed from 3 samples of ricefields and 3 samples of wheatfields of the same size (about 60 pixels) on July 23 and August 11. Figure 4 shows examples of ricefield and wheatfield histograms

The wide range of ricefield responses in June and July can be explained by the different growth stages of the riceplants in different parcels : beginning of the tillering, beginning of the stem elongation, boots just visible. The water layer appears through the vegetation and the response of one parcel can differ from that of its neighbour. In August, ricefields are at the beginning of the heading, the fields are then well covered by the vegetation and the responses are more uniform.

In figure 5, several field categories are studied by diagramming MSS 5, MSS 7 sample responses from the July 6, July 23 and August 11 images. Responses of ricefield appear in July images as a cluster which can be separated from the others, meanwhile for August date, ricefields and vineyards are merged in one cluster.

In the vegetative stage of the rice plant, there is a correlation between responses of vegetation and water, and the correlation coefficient

$r = \frac{\sigma_{x_i y_i}}{\sigma_x \cdot \sigma_y}$ is greater than that of other field categories, where σ_x and σ_y are standard deviations of MSS 5, MSS 7 responses. As an example, correlations coefficient computed from July 6 are the following :

	$\sigma_{MSS 5}$	$\sigma_{MSS 7}$	r
rice	4.37	6.44	- 0.117
vine	4.48	3.57	- 0.012
wheat	7.57	5.15	- 0.005

For the July images, the fastest method for distinguishing ricefields can consist of choosing a linear classifier in the MSS 5 - MSS 7 plane.

4.2 DATA REDUCTION

To reduce the dimension of multitemporal Landsat data, Sebastien discrimination criterium (4) is applied on samples of the main field categories : ricefield, wheatfield, vineyard extracted from July 6, July 23 and August 11 Landsat images.

The samples are divided arbitrarily into 2 groups. The discriminant function

$$d^2(x, Y_k) = S_k^{-1/n} ((x - E(Y_k))^t S_k^{-1} (x - E(Y_k)) + n)$$

with Y_k : set of K^{th} samples ($k = 1, 2, 3$)

S_k : covariance matrix of Y_k

n : number of channels

E : expectation function

computed on the first group, is then applied to the second for calculation of the "well-classed" sample percentage. Combinations of 1, 2, 3, 4, 5... channels among the 12 are computed in order to determine the best one for discriminating

ricefield, wheatfield and vineyard.

Table 5 results calculation of "well-classed" percentage with data from different date and band and shows in the 3 cases the best combinations of 2, 4, 5 channels among the 12.

The August image appears the best for ricefield recognition : the ricefield response is then well separated from that of wheatfield (harvested) and vineyard. 90 % of ricefield can be computed from only MSS 5, MSS 7 images. Unfortunately, for inventory purpose, the August image cannot be used without combination with an other date data, the test site being partly cloud covered.

4.3. CLASSIFICATION METHODS

Unsupervised and supervised methods have been applied to a limited test-site for evaluating the efficiency of the methods compared with ground determinations.

4.3.1. UNSUPERVISED METHOD : the unsupervised method evolved is a mobile center clustering technique called "Nuées Dynamiques" by E. Diday (5). The principle of the method consists of settling clusters around centers G_C^1 chosen randomly on the image. In the next step the process is iterated, i.e. new centers $G_C^2, G_C^3 \dots G_C^n$ must be built and stopped when the centers remain fixed, i.e. when $G_C^n = G_C^{n+1} \forall C$.

The method is justified by the fact that the passage from G_C to $G_C^1, G_C^2 \dots$ reduce the intra-class variance of E_C .

To reduce the number of iterations, the area under study is divided into subareas, each of which is a square of 60 x 60 pixels.

Z_{11}	Z_{12}	Z_{13}
Z_{21}	Z_{22}	Z_{23}
Z_{31}	Z_{32}	Z_{33}

The process is applied first to Z_{11} . The iteration number is limited to 5. If after 5 iterations, the convergence of the process is not reached, an other random choice is made. When the convergence on Z_{11} is obtained, zone Z_{12} is computed with the last set of centers of Z_{11} .

In the case of Landsat imagery, every sub-area corresponds to a zone of about 4.8 km x 3.6 km. Geographically, in such an agricultural zone, 2 contiguous subareas are in most case included in the same ecological region. This means that the same types of vegetation or land use will very probably be found in 2 contiguous subareas. So, in practice, one iteration is necessary for computing Z_{12} with the last centers of Z_{11} . If however the "landscape" changes suddenly, then other iterations are needed, or a choice of random initial center must be made. The contiguity concept can be applied in both directions, i.e. lines and columns. Thus for Z_{21} , the initial centers came from Z_{11} .

4.3.2. SUPERVISED METHODS : several methods are applied, but parametric method such the maximum likelihood ratio is not utilized by the fact that the normal hypothesis for ricefield responses is not proved and the a priori occurrence probability of classes are unknown.

- Barycentric method : using weighed euclidean distance as discriminant function :

$$d^2(x_1, x_2) = \sum_{i=1}^n K_i (x_{1i} - x_{2i})^2$$

K_i : weighting factor for channel i. The principle consists to choose K_i to get a maximum of well classed prototypes. The process starts with

$$K_i = \frac{1}{\sigma_{ii}^2}, \text{ where } \sigma_{ii}^2 \text{ is the total variance of prototype in channel i.}$$

- Quadratic method : using Sebastien (4) discriminant function.

- Fix-Hodges method (6) : using Mahalanobis distance and generalizing the K-Nearest-Neighbour rule.

- Chi-Square-method : using χ^2 distance as classifier :

$$d^2(x_1, x_2) = \sum_{i=1}^n K \left[\frac{x_{1i}}{\sum_{i=1}^n x_{1i}} - \frac{x_{2i}}{\sum_{i=1}^n x_{2i}} \right]^2$$

4.3.3. COMPARATIVE STUDY : to illustrate the efficiency of the methods, different algorithms are performed on August 11 LANDSAT data, pointed out as the best date for ricefield inventory, according to results of the data reduction study.

Figure 6 shows a 6.7 x 9.5 km area of the test site (120 pixels x 120 pixels) with the location of some field categories : ricefields in dark grey, vineyards in medium grey and wheatfields in light grey. Different results are studied :

- Barycentric and quadratic methods : the reference ricefields are mapped (figure 7) with 3 % of difference between computed surface and owner estimation. Vineyards are subdivided into 2 classes, relating to their soil conditions.
- Fix-Hodges method : ricefields are mapped with 5 % of divergence. Vineyard is classified as one class, including meadows, market garden and bare soil. For ricefield, the method can fit to their non normal spectral responses. However, it requires a very good sample selection which is difficult to perform on such parcelled agricultural site.
- Unsupervised methods : results are obtained with clustering techniques using euclidean, Mahalanobis and χ^2 distance. The ricefields and vineyards are partly merged as expected, according to diagram 5C, while wheatfields are divided into 2 classes which do not correspond to differences in cultural conditions.

Figure 8 shows an example of unsupervised method applied on the site, using Mahalanobis distance.

Table 6 compares areas in hectares of some most important fields computed by different techniques with owner estimations.

The computer CP time for supervised methods is 0.5 sec for 60 x 60 pixels and 5 classes. However, for Fix-Hodges discrimination, the training phase for 750 samples is about 5 sec. For clustering techniques, computer CP time is function of the iteration number, each iteration taking about 1 sec. In practice, 3 iterations are required for the first subarea and one iteration for the followings then for 120 x 120 pixels, about 10 sec are required.

4.4. TEXTURE ANALYSIS :

Texture analysis is attempted on 1500 m IR B&W imagery by edge detection and study of the texture within detected fields.

4.4.1. EDGE DETECTION : the algorithm uses discrete operators to detect edges of several fields and marshes in the image. The gradient of grey level is replaced following Eberlein-Beszka's method by (7)

$$G_x(i,j) = \text{DIF}(i,j) \quad , \quad \text{where} \quad \begin{array}{cc} a & b \\ & x \\ d & c \end{array}$$

$$G_x(i,j) = ((a-x)^2 + (b-x)^2)^{1/2} \quad \text{and}$$

$$\text{DIF}(i,j) = x - \bar{x} \quad , \quad \bar{x} = (a + b + c + d + x)/5$$

The edge detection is computed by an algorithm starting on the maximal gradient point on the image and following the line of minimal slope. The chain is stopped when either a low threshold, or a point belonging to a previous computed chain is reached.

Figure 9 shows result of edge detection technique computed on part of the aerial image (figure 2).

4.4.2. TEXTURE PROPERTY : by analyzing the frequency distribution of the values of the field local property, one can obtain invariant properties of the field. Statistics of local properties - called textural properties - can be served as a decision rule. In table 3 and 4, parcels of early growth stage

riceplants (June, July) are characterized by the wide range of their responses with regard to the other parcels. This property is used to recognize ricefields.

4.5. EVALUATION OF UNPRODUCTIVE SURFACE :

With the resolution of Landsat, ricefields are mapped including roads and dikes (4 - 5 m width). For a statistical evaluation of the "unproductive" surface, several ricefields are studied from 1500 m aircraft image (June 20) by means of histograms. In most case, the road responses differ from that of flooded ricefields and a density slicing provides ratio of road area on the total. The percentage averaged over 9 representative ricefields is 17,2 %.

4.6. CONCLUSION

For the best use of Landsat and aerial data for ricefield mapping purpose, the conclusion drawn from the 1975 data on the French test-site are as follows :

- June 20 : - recognition of ricefield by edge detection and texture analysis (aerial image)
 - evaluation of unproductive surface within a block of ricefield (aerial image)
- July 6 : - classification by linear discrimination (LANDSAT)
- July 23 : - (confusion with marshes is possible)
- August 11 : - classification by barycentric or quadratic distance
- Jul.6-Aug.11 : - classification using barycentric distance on MSS 7 - MSS 5 bands of the 2 dates
- Jul.6-Jul.23-August 11 : - classification using barycentric distance on MSS 7 - MSS 5 bands of August 11, MSS 7 band of July 6, MSS 5 band of the July 23 images.

The inventory method using barycentric distance on the last data combination gives about 12 000 hectares within the test-site, while the value given by the agricultural statistics is 10 500 hectares. Figure 10 shows result obtained on the sub-test-site N° 1 (Arles area), the darkest sign corresponding to ricefield.

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date of passage	Delta	growth stage Euribe	Balilla 28	soil condition
April 7	-	-	-	wet
April 25	-	-	-	dry
May 13	Emergence	Emergence	Emergence	under water
May 31	Emergence	Emergence	Emergence	" "
June 18	Beginning of tillering	Emergence	Emergence	" "
July 6	Beg. of stem elongation	Beg. of tillering	Beg. of tillering	" "
July 24	Boots just visible	Beg. of stem elongation	Beg. of stem elongation	" "
Aug. 11	Mid flowering	Beg. of heading	Boots just visible	" "
Aug. 29	Early milk stage	Mid flowering	Mid flowering	" "
Sept. 16	Early dough stage	Early milk stage	Early milk stage	" "
Oct. 4	Caryopsis loosening at daytime	Caryopsis hard	Early dough stage	Partly at zero level
Oct. 22	-	Caryopsis loosening at daytime	Caryopsis hard	-
Nov. 9	-	Harvested	Harvested	-

TABLE 1. GROWTH STAGES OF RICEPLANTS AND SOIL CONDITIONS during the passages of LANDSAT 2, 1975.

dates	Objective	remarks
May 13	Ricefield inventory	Result includes natural water bodies
May 31	" "	Perturbation : rain gauge reading = 11 mm
June 18	" "	Several ricefields were dried out for weed killer treatment
July 6	" "	Result includes ricefields and marshes
July 24	" "	Result includes ricefields, marshes and temporarily flooded plots (vineyards, wheatfields after harvest...)
August 11	Ricefield inventory and disease detection	
Sept. 16	" "	
October 4	Mapping of rice varieties	

TABLE 2.

SAMPLE	MEAN VALUE	STANDARD DEVIATION
Ricefields	19.32	9.39
	39.98	10.22
	18.83	5.57
	32.51	11.45
	15.95	5.29
Wheatfields	20.07	2.64
	17.89	3.87
	20.48	4.60
Meadows	28.48	3.29
	25.52	4.41
	23.42	4.06

TABLE 3. STATISTICS OF SOME FIELD RESPONSES
June 20. 1975.

Date	samples	MSS 5		MSS 7	
		mean value	standard deviation	mean value	standard deviation
July 23 1975	Rice	28.86	5.46	31.79	3.95
		23.58	6.31	29.08	5.09
		33.50	4.68	31.08	4.12
	wheat	43.04	2.10	23.03	1.16
		46.71	2.16	27.75	1.03
		41.71	1.95	24.20	1.38
Aug. 08 1975	Rice	22.31	1.27	36.18	3.26
		19.95	1.30	35.75	2.45
		18.29	1.73	37.48	2.54
	wheat	38.92	4.01	46.86	3.92
		40.50	3.13	51.21	3.43
		31.21	2.92	37.85	5.80

TABLE 4. STATISTICS OF SOME FIELDS LANDSAT
RESPONSES

	MSS 7, MSS 5 Aug.11			MSS 7, MSS 5 Aug.11 MSS 7 July 6 MSS 4 August 11			MSS 7, MSS 5 Aug. 11 MSS 7 July 6 MSS 4 August 11 MSS 5 July 23		
computed original	rice	wheat	vineyard	rice	wheat	vineyard	rice	wheat	vineyard
rice	209	11	12	214	5	13	214	5	13
wheat	3	172	33	12	176	20	7	183	18
vineyard	12	7.	79	3	9	86	3	96	89
	well classed percentage : 85,50 % well classed percentage for rice : 90 %			well classed percentage : 88.48 % well classed percentage for rice : 92 %			well classed percentage : 90.33 % well classed percentage for rice : 92 %		

TABLE 5

	Les Pébrières Rice	Les Huits Clos Rice	Mas du Tort Rice	Mas de Vert Vineyard	Dom. de la Reine wheat
Owner estimation	43	189	95	84	111
Barycentric	45	177	82	82	113
Quadratic	47	195	86	73	115
Fix-Hodge	46	198	71		117
Clustering- euclidean d.	46	190	94	72	52 + 67
Clustering- Mahalanobis	42	157	66	73	88
Clustering- x ² d.	45	157	87	77	53 + 67
Clustering- 4 classes	44	198	87	63	102
Clustering- 6 classes	40	106 113 +	62 17 ⁺	58	41 + 62

TABLE 6. COMPARISON OF FIELD AREA COMPUTED FROM
LANDSAT DATA WITH OWNER ESTIMATION.

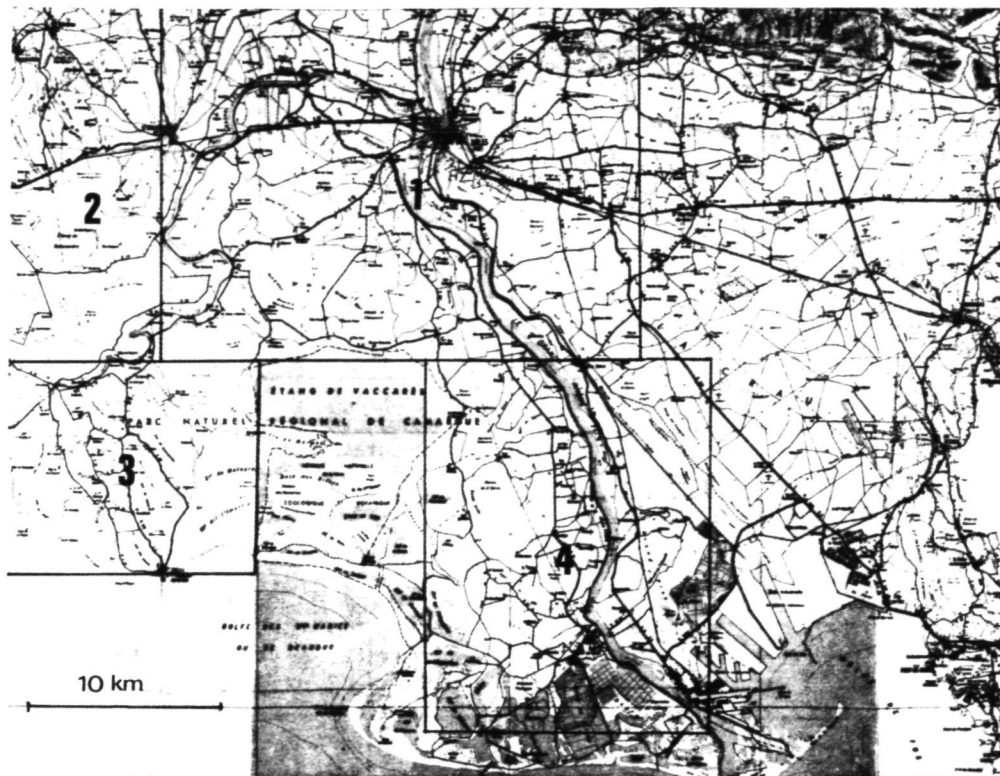


FIGURE 1 . CAMARGUE FRENCH TEST SITE. (4 subareas).



FIGURE 2. PART OF 1500 m AERIAL
IMAGE.
(1) : block of ricefield.

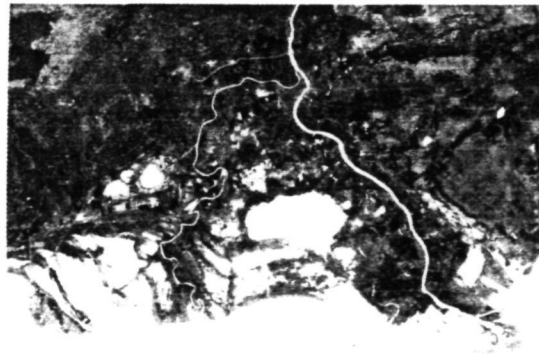


FIGURE 3. LANDSAT IMAGE ENLARGEMENT
MSS 7 - July 23 -
Scale ~ 1/750 000 .

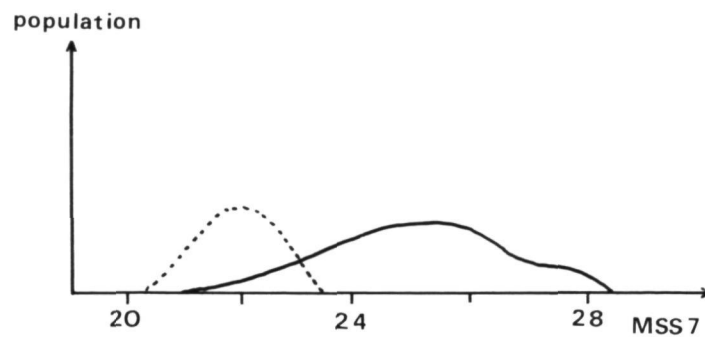
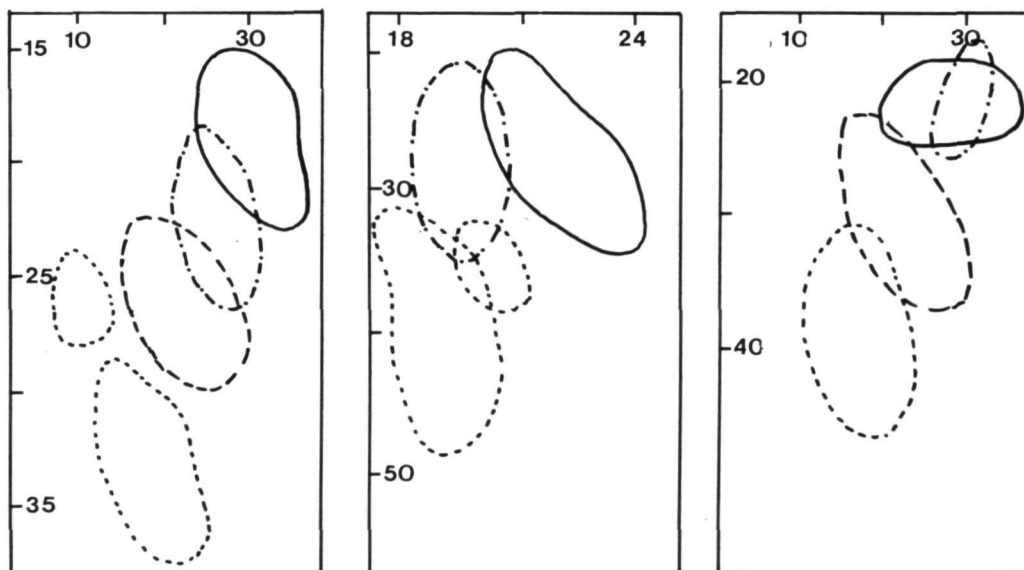


FIGURE 4. EXAMPLES OF HISTOGRAM - July 6 image.
- rice, wheat.

MSS 7



MSS 5

a : July 6

b : July 23

c : August 11

FIGURE 5. MSS 5 - MSS 7 response diagrams.
— rice, ... wheat, .-.- vineyard.
--- marshes

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OF POOR QUALITY



FIGURE 6. GEOGRAPHICAL MAP.
Part of the test-site.



FIGURE 7. CLASSIFICATION RESULT :
supervised method,
barycentric distance, dark grey:rice.



FIGURE 8. CLASSIFICATION RESULT :
unsupervised method.



FIGURE 9. RESULT OF EDGE DETECTION
TECHNIQUE applied on
figure 2.



FIGURE 10. CLASSIFICATION RESULT : barycentric distance.
July and August data. Dark gray: ricefield.

FORESTLAND TYPE IDENTIFICATION AND ANALYSIS IN WESTERN MASSACHUSETTS:

A LINKAGE OF A LANDSAT FOREST INVENTORY TO AN OPTIMIZATION STUDY

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ABSTRACT

Digital land cover files derived from computer processing of LANDSAT and soil productivity data are linked and used by linear programming model to determine production of forested areas under different management strategies. Results of model include maps and data graphics for four-county region in western Massachusetts.

1. INTRODUCTION

A number of natural resource planning programs involving Federal, state, and local governments are in operation. One of these is the Cooperative River Basin Studies (CRBS) which is responding to Section 6 of Public Law 83-566 established in 1954. This program is to identify and delineate the severity and extent of natural resource problems in river basins, and to identify those problems amenable to solution by government and private programs. The analysis required by the CRBS program and similar studies in forested areas requires a detailed examination of alternative land use strategies and the impact of these strategies on environmental and economic issues. A system which supports this analysis and its link to LANDSAT and other data sources is demonstrated in the following pages. The system provides outputs responsive to the needs of planners and decision makers in both the private and public sectors.

2. METHODOLOGY

2.1 ANALYTICAL SYSTEM

The Resource Analysis Procedure (RAP) (Ref 1) is a computer software package consisting of three internally linked components: a data base, a computer composite mapping system, and two mathematical programming algorithms. RAP was developed by the Bureau of Economic and Business Research at the University of Utah for Northeastern Area - State and Private Forestry, USDA Forest Service. The procedure is an outgrowth of various existing systems including the Composite Mapping System (CMS) and the Functional Mathematical Programming System (FMPS) (Ref 2). The CMS was developed by Consolidated Analysis Centers Inc. (CACI) for the Economic Development Administration (EDA) of the Department of Commerce. The CMS system grew out of a basic technique used by Dr. George Nez.

RAP enables resource planners to perform optimization or simulation analyses and to produce maps and data graphics of the solutions in various alphanumeric formats. It also produces histograms of distributions and maps of time-dependent and/or geographically dependent data. Finally, maps are produced that express relationships among geographic areas based on single or multiple topic characteristic terms aggregated to meet user specifications.

A mathematical programming model is used for spatial optimization analysis in which quantities and locations (right hand side constraints) of usable resources are automatically generated using the data base and composite mapping routine. The model's final basis solution is mapped to show the location of both limiting resources used and products produced.

2.2 DATA GENERATION

Digitized maps and external files are used in developing spatially dimensioned data, which are processed by the RAP system. Major land cover and land use files are produced by the Bendix Aerospace Systems Division from LANDSAT CCTs, and by the US Geologic Survey from aerial photography for its LUDA (Ref 3) program. The US Bureau of Census DIMECO and URBAN ATLAS files and the USDA Forest Service COMLUP files are also potential inputs.

The major RAP inputs for this investigation were digital land cover and soil productivity files for the counties of Berkshire, Franklin, Hampden, and Hampshire in western Massachusetts (Figure 1), an area of about 2,500 square miles.

The digital land cover inventory was produced on the Bendix Multispectral Data Analysis System (MDAS) (Ref 4) from LANDSAT computer compatible tapes (CCTs) collected over the test site on 31 August 1976 (Scenes 5500-14151 and 5500-14153). These processing techniques (Ref 5, 6) have been under continuous development at Bendix for the past 9 to 11 years, primarily using aircraft multispectral scanner (MSS) data and more recently using satellite MSS data.

For this inventory, the LANDSAT CCTs were transformed into interpreted land cover files for the sixty-three (7.5-minute quad) maps covering the study area. A data sample within each file had a north-south grid orientation covering an area of 31.6 by 57.9 meters and was coded to identify land cover within that sample. Of interest to this study were codes identifying the two forest types — hardwoods/mixedwood and softwood. The mixedwood could not be reliably separated from the hardwoods due to the severe channel banding (noise) in the LANDSAT scenes and the uneven solar illumination of the western Massachusetts hills at 9:30 a.m. Other scenes should permit this separation. Supporting information used to process LANDSAT tapes included detailed land cover maps produced by Massachusetts Map Down (Ref 7).

Maps provided by the Soil Conservation Services were interpreted and digitized into two soil productivity groups representing medium (50-85 Cu Ft/Ac) and low (0-49 Cu Ft/Ac) forest capabilities. The two forest types were aggregated into a forestland category and composited on the two soil groups. This composite generates spatially dimensioned input data used to constrain the optimization model.

3. MODEL STRUCTURE

The optimization model is a linear programming formulation representing production capabilities of counties in the study area. The model performs three functions: (1) identifies production levels possible under alternative management strategies, (2) allocates resources available in each county among strategies, and (3) geographically locates and simulates the impact of strategies on the resource base.

Three management strategies were used: (1) present condition, (2) maximum multiple use, and (3) maximum fiber. The present condition strategy represents management as presently practiced. This strategy is extensive, using no capital investment to increased production. The maximum multiple use strategy uses all activities that economically maximize product outputs. The maximum fiber strategy emphasizes harvest and utilization of wood fiber by reducing other product output as needed to meet a goal. These latter two strategies involve long-term capital investment to improve production potential. All three strategies could be used in Berkshire and Franklin Counties. Only the present condition and maximum fiber strategies could apply in Hampden and Hampshire Counties.

All three management strategies generate multiple outputs, which include sawtimber, pulpwood, wildlife, general recreation, special recreation, sediment, and stream flow. Market prices are attached to wood products, while prices for other outputs are based on previous research.

The strategies were applied to the forest/soil composites using the optimization model. It was reasoned that investment would occur on higher productivity sites that would yield the most return per dollar invested. Consequently, the maximum multiple use and maximum fiber strategies, which involve long-term investments, were applied only to forestland on medium productivity soil. The present condition strategy applied only to forestland on low productivity soil.

4./ ANALYTICAL RESULTS

4.1 RESOURCE AVAILABILITY

The 2,500 square mile, four-county study area and its relationship to the rest of Massachusetts is shown in Figure 1. The study area represents approximately 30% of Massachusetts, with heavy forests, substantial agricultural, and recreational resources. The Connecticut River Valley is within its boundaries.

Table 1 shows the medium and low soil productivity group acreages in each of the four counties in the study area. Figure 2 shows the geographic distribution of these two productivity groups in each county.

Table 2 and Figure 3 show the acreage and spatial distribution, respectively, of hardwood/mixed and softwood forest types in the study area. This information was derived directly from the digital land cover files produced from the computer processing of LANDSAT CCTs. As can be seen, there are very few stands of pure softwood in the area studied.

The synthesis of forest cover and soil productivity groups are shown as acreage in Table 3 and geographic distribution in Figure 4. Direct interpretation of the composited map data provided both the tabular output in Table 3 and the resource data that were read directly into the right hand side constraint column of the linear programming model. Table 4 and Figure 5 represent refinements in the tabulation and geographic distributions of resource data input to the linear programming model. The acreage amounts and geographic locations of hardwoods/mixed and softwood types on medium and low soil productivity groups are determined.

4.2 OUTPUTS PRODUCED

Each management strategy produced seven products. As shown in Table 5, only the present condition and maximum fiber strategies were used in this production process. The present condition strategy applied only to the lower productivity group, while the maximum fiber strategy applied to the medium quality productivity group. This situation held in each of the four counties in the study area.

The objective function value for this model was \$19,797,272, representing net value after removal of operating and investment costs. The marginal value products shown in Table 6 represent the amounts by which the objective function would increase if one more unit of the resource were available for use. Two additional facts regarding a maximum multiple use strategy emerged in Berkshire and Franklin Counties. For every unit of limiting resource forced into use by this strategy in Berkshire County, the objective function would be reduced by \$0.86. A similar action would cause a reduction of \$0.14 per unit in Franklin County.

4.3 MANAGEMENT STRATEGIES EMPLOYED

These strategies reflect present management alternatives in Massachusetts. They are not positions on the production surface representing maxima. The strategies are suboptima biologically, but may represent constrained optima recognizing local cultural conditions and general management objectives. They represent aggregates of all forest types in the individual counties. The output levels per acre are weighted averages over the soil productivity group and forest types.

Table 7 reflects the solution to the optimization model. It contains the acreage distributions for management strategies on forestland by soil productivity group in each of the four counties. Figure 6 shows the geographic distribution of these management strategies. This map shows where productive activities occur but does not show the amount of production per acre because the management strategies employed yield joint-products. If each strategy produced only one product instead of the present seven, it would be possible to directly interpret production levels from the maps. Figure 6 is the mapped linear programming solution which adds the desired spatial dimension to the optimization analysis.

5. SUMMARY

This work demonstrated the use of LANDSAT digital land cover files as a directly readable RAP data source for analysis involving linked use of mathematical programming and computer composite mapping of a forested study area in western Massachusetts. Production constrained to forested areas on two soil productivity groupings was determined through linear programming. A spatial dimension was added using computer composite mapping. This spatial aspect is

emphasized; without it, the results of planning efforts have limited impact on the public for whom they are intended.

Two major caveats regarding interpretation of the results are warranted. First, the management strategies are based on informed judgment of field personnel and probably do not represent production frontiers. (Since this is a linear model, constant returns to size and scale are assumed.) Second, the model used is a simple one that was derived from a larger more complex model of the full state's forest economy. Due to time constraints and expositional simplicity, this generality was necessary.

6. REFERENCES

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Acknowledgment: Dr. Gary Rockwood of the Bureau of Economic and Business Research, University of Utah, collated the soil productivity data with the Landsat forest categorization, and produced figures 2 through 6 in this paper.

TABLE 1. MEDIUM AND LOW SOIL PRODUCTIVITY GROUPS' ACREAGES IN STUDY AREA COUNTIES

Counties	Soil Productivity Groups	
	Medium (Acres)	Low (Acres)
Berkshire	473,615.77	136,701.02
Franklin	169,095.17	283,018.03
Hampden	307,749.67	87,773.90
Hampshire	218,647.99	170,845.99

TABLE 2. FOREST TYPE ACREAGES IN STUDY AREA COUNTIES

Counties	Forest Types	
	Hardwoods/Mixed (Acres)	Softwoods (Acres)
Berkshire	448,552.46	944.09
Franklin	371,973.47	468.78
Hampden	250,605.66	471.99
Hampshire	274,647.61	941.64

TABLE 3. FORESTED ACREAGE ON SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES

Counties	Soil Productivity Groups	
	Medium (Acres)	Low (Acres)
Berkshire	327,847.41	116,471.48
Franklin	138,634.28	233,341.05
Hampden	216,143.70	28,315.80
Hampshire	173,965.75	101,623.60

TABLE 4. FOREST TYPE ACREAGES ON SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES

Counties and Soil Productivity Groups	Forest Types	
	Hardwoods/Mixed (Acres)	Softwoods (Acres)
Berkshire		
Medium	327,375.18	472.23
Low	116,471.48	0
Franklin		
Medium	138,634.28	0
Low	232,872.27	468.78
Hampden		
Medium	216,143.70	0
Low	27,843.81	471.99
Hampshire		
Medium	173,965.75	0
Low	100,681.97	941.64

TABLE 5. PRODUCT OUTPUTS FROM FORESTED LANDS IN STUDY AREA COUNTIES

Counties and Management Strategies	Products						
	Sawtimber (MCF)	Pulpwood (MCF)	Wildlife (AUM)	General Recreation (VD)	Special Recreation (VD)	Sediment (Tons)	Streamflow (Acre-Ft)
Berkshire							
Present Condition	571	12	338	243,424	54,741	3,844	125,789
Maximum Fiber	3,246	1,508	951	698,314	154,088	11,475	750,770
Franklin							
Present Condition	1,493	70	583	256,675	252,008	51,335	235,674
Maximum Fiber	1,150	180	347	156,656	159,429	33,272	288,359
Hampden							
Present Condition	119	6	71	37,376	30,580	623	56,913
Maximum Fiber	2,075	2,161	778	285,309	265,856	4,842	481,999
Hampshire							
Present Condition	742	41	701	238,814	110,769	2,236	202,230
Maximum Fiber	2,157	887	1,200	450,569	436,652	4,175	356,628
Total	11,553	4,865	4,969	2,358,137	1,464,123	111,802	2,498,362

TABLE 6. MARGINAL VALUE PRODUCTS FOR SOIL RESOURCE IN STUDY AREA COUNTIES

Counties and Soil Productivity Groups	Marginal Value Products (Dollars)
Berkshire	
Medium	14.24
Low	12.51
Franklin	
Medium	12.32
Low	12.74
Hampden	
Medium	16.48
Low	14.83
Hampshire	
Medium	19.75
Low	15.48

TABLE 7. MANAGEMENT STRATEGY ACREAGES ON FORESTED SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES

Counties and Forested Soil Productivity Groups	Management Strategies	
	Present Condition (Acres)	Maximum Fiber (Acres)
Berkshire		
Medium	----	327,847
Low	116,471	----
Franklin		
Medium	----	138,634
Low	233,341	----
Hampden		
Medium	----	216,143
Low	28,315	----
Hampshire		
Medium	----	173,965
Low	101,623	----

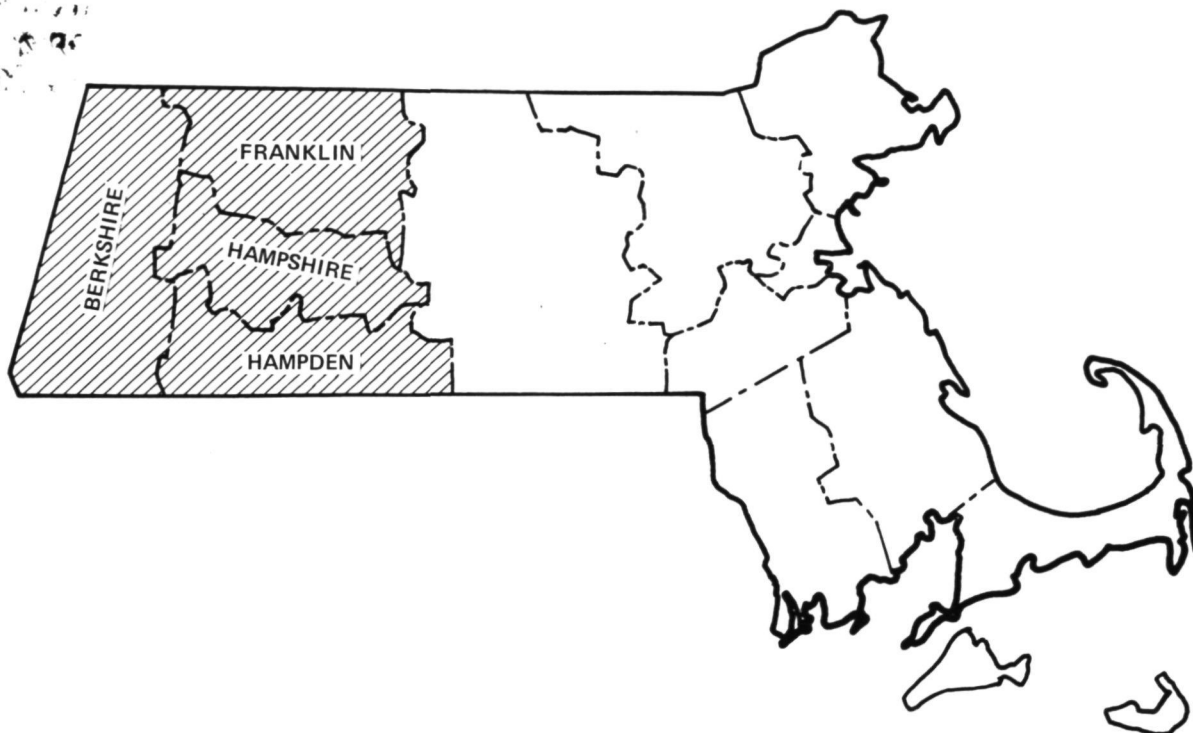


FIGURE 1. FOUR-COUNTY STUDY AREA IN MASSACHUSETTS



FIGURE 2. MEDIUM AND LOW SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES



FIGURE 3. FOREST TYPES IN STUDY AREA COUNTIES



FIGURE 4. FORESTED SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES



FIGURE 5. FOREST TYPED SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES



FIGURE 6. MANAGEMENT STRATEGY DISTRIBUTIONS IN THE STUDY AREA

LARGE SCALE 70mm PHOTOGRAPHY FOR
RANGE RESOURCES ANALYSIS IN THE WESTERN UNITED STATES

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ABSTRACT

Large scale 70mm aerial photography is a valuable supplementary tool for rangeland studies. A wide assortment of applications have been developed varying from vegetation mapping to assessing environmental impact on rangelands. Color and color infrared stereo pairs are useful for effectively sampling sites limited by ground accessibility. They allow an increased sample size at similar or lower cost than ground sampling techniques and provide a permanent record.

1. INTRODUCTION

Rangelands cover almost 40 percent of the globe. These are lands that are not forests, agricultural, urban or industrial lands and are used for the purpose of providing forage for both domestic and wild animals, wildlife cover, recreation opportunities and vegetation for watershed protection. They are grasslands, shrublands, semi-arid deserts, marshlands and grazed forest and open woodlands. The broad expanses of these landscapes often coupled with relatively low productivity when compared with timberlands and intensive agricultural lands has precluded intensive analysis and monitoring. Remote sensing techniques including color and color infrared photography are rapidly being developed for rangeland applications and are proving to be extremely useful.

For the past 9 years this author has been involved in the obtaining and applications of large scale color and color infrared photography for evaluating range resources in the western United States. Large, intermediate and medium scales (Heller 1970) are represented here as this paper refers to representative fraction scales of approximately 1:15,000 up to as large as 1:600. At the largest scale this translates to 1 inch equals 50 feet. Emphasis of this paper is on these largest scale photographs.

These photographs have been obtained and interpreted in numerous ways. Most often these photographs have been used as an appropriate large scale subsample as part of a multistage sample while in other cases the data stand alone as a means of studying a small specific location with great detail. The various uses have included studies of the following: vegetation and species identification, plant species mapping, vegetation mapping, plant cover determination, plant density counts, biomass or range productivity determinations, vegetation utilization, plant vigor and phenology, range readiness, erosion determinations, rodent activity, off-road vehicle use and/or damage, evaluating herbicide applications, range condition and trend and evaluating and measuring environmental impact.

Numerous papers have described the applications and benefits of large scale color and color infrared photography for range resources management (Driscoll and Reppert, 1969; Carneggie, 1968; Lorain 1970; Carneggie, 1971; Carneggie et al., 1975; Tueller et al., 1972; Tueller and Swanson, 1973; Cosgriffe et al., 1973; Driscoll, 1969a and 1969b; Tueller and Booth, 1975; Tueller and Clark, 1976; Young et al., 1976; and Booth, 1974). Lorain (1970) and Francis (1970) have described techniques for marking transects for easy viewing from the air. Booth (1974) and Tueller and Booth (1975) describe procedures for systematically sampling range ecosystems.

2. METHODS

The equipment that we have used for the acquisition of these photographic data has consisted of a light single engine fixed wing aircraft (usually a Cessna 206, 185 or 180) equipped

with an 18" camera hatch, two Hulcher 103, 70mm rapid sequence cameras, two 12-volt batteries, a dual camera mount (fabricated in our laboratory), a light meter and often an intervalometer. Applications and technology for large scale 70mm photography has been developed and successfully applied in the study of vegetation on rangelands, forests, and production agriculture (Aldrich et al. 1959; Heller 1959; Aldrich 1966; Heller 1970 and Reppert 1969).

The Hulcher^{1/} rapid sequence cameras are capable of being exposed singly, at five frames per second, ten frames per second, or pulsed at a given frame rate with an external intervalometer. Most photographs were taken with a 150mm Schneider-Xenotar F2-8 lens using one of three films: Aerochrome infrared film type 2443 (Kodak), color negative film type 2445, and Ektachrome MS aerographic film type 2448. Normally, color and color infrared films are used with simultaneous framing.

All photographs were obtained with stereo overlap for three-dimensional viewing. This was accomplished with each single camera by coordinating aircraft ground speed, altitude and frame rate. For example, to obtain between 60 and 80% stereo overlap and a 1:600 scale, it was necessary to fly the aircraft at 100 mph ground speed at 300 feet above terrain exposing each frame at 1/1500th of a second (Aldrich et al. 1959). Stereo viewing was found to be necessary for all our applications.

Our experience in the Great Basin suggests that the best results are obtained when the photography can be obtained on a clear day with the sun near its zenith. The data are usually studied directly in the roll as transparencies by stereoscopic viewing. Only if the range researcher or manager requires visual material for reports or public display is it necessary to process to prints. This is an important advantage since color prints at sizes larger than contact are relatively expensive. The 70mm or 2.25" format is more than adequate for evaluation although in some cases it has been necessary to project the transparencies before certain detailed measurements could be made.

Photographic costs are variable and generally the aircraft operation or rental is the major cost. Suitable light aircraft presently rent without pilot for from \$40-85/hour while prices including a pilot are normally \$10-20/hour higher. A 100-ft. roll of color or color infrared film now costs approximately \$160 to purchase and process to the transparency. A 100-ft. roll will cover approximately 72 acres at a scale of 1:800 although this kind of continuous coverage is rarely accomplished or required for most 70mm work. A single roll can usually provide up to 450 single frame or over 150 stereo pairs. In other words, numerous areas can be sampled for range resource analysis with a single roll of film.

The promoter of large scale color photography for rangeland uses should be the first to strongly state that these photographic data, good as they are, do not constitute a panacea or final solution to some of our range sampling problems. Rather, they, in my opinion, provide an excellent cost-effective supplement for our range analysis and monitoring problems. They, ideally, should be used by trained range resource managers and scientists to supplement their field work. Those intimately familiar with the field problems will find 70mm color photography a valuable supplementary tool for their work.

Of even greater importance is the fact that photographs provide a permanent record that can be reevaluated and reinterpreted 5, 10, and 50 years from now if the need arises. Field notes and measurements, while required, cannot be re-measured due to the dynamic nature of our range resource. Also, acquisition of the data is not dependent on ground accessibility.

We have spent considerable time developing dichotomous keys for use in aerial photo interpretation. The keys use most of the various photo interpretation factors such as texture, shape, size, tone and pattern to distinguish range resource features. Color has been used as a criterion but found wanting due to the extreme variation found from date to date in color and especially in the color infrared film. These keys seldom work if used by untrained range managers or scientists without field experience or someone outside the field. On the other

^{1/} I do not wish to particularly endorse one camera over another. However, the Hulcher 103 camera was within our price range, accomplished our tasks and after gaining some experience they have performed up to and often beyond our expectations.

hand, they do strongly aid the knowledgeable range person as he tries to familiarize himself with the aerial photography. Several of these keys are available for use and review (Tueller et al. 1972); Tueller et al. 1975; Seher and Tueller 1973; Lorain 1970; Tueller and Lorain 1971; Parkin 1977).

2. APPLICATIONS

Species Identification

The accurate identification of species is almost always a necessary first step before other plant association or soil surface parameters can be assessed photographically. Most, if not all, trees and shrubs on all range sites can be correctly identified (Tueller et al. 1972). Only certain species of forbs and grasses can be correctly identified and subsequently measured (Driscoll and Reppert 1968; Carneggie et al. 1971; Poulton et al. 1975). Normally these latter species must be either those that are abundant or large and showy or both. Dichotomous keys utilize several interpretation factors such as color, texture of individual plants or plant clumps, pattern of the distribution of individuals and shape of certain species are very valuable for photo interpreters involved in species identification (Lorain 1970; Tueller et al. 1972). Color and color infrared are likewise important in the species identification process and in every case additional species are identified as the second film type is interpreted. On some sites color alone is preferable to color infrared (e.g. Sonoran Desert sites).

Plant Cover

In a range vegetation context the reference here is to foliar projection of shrub and forb vegetation onto the ground and usually to the basal area of grasses. Several methods have been used: planimeter, point method or dot grid, estimation, line intercept and direct measurements involving the measurement of two radii and then computing cover with the ellipse formula. The point method or dot grid has perhaps been the most useful and most accurate (Tueller and Lorain 1973). For the future we can expect to use an electronic planimeter, an area evaluator circuit with a color density slicing apparatus, or a scanning microdensitometer (Driscoll et al. 1974) to rapidly obtain and record cover data.

Cover data by species can be as much as 30 times slower using routine field procedures when compared with the same data from large scale aerial photographs by dot grid (Tueller et al. 1972). Ground and photo data is often very comparable by species and for total plant cover (Table 1 and Tueller and Lorain 1973).

Plant Density

Density (plants/unit area) is obtained with ease for some species, especially those that are readily identified. However, the ground density data cannot be duplicated on the aerial photographs as readily as can cover measurements (Table 2 and Lorain 1970). In some cases, individual specimens cannot be distinguished, e.g., some shrubs occur as clumps averaging one to several specimens. In this case it is often possible to enumerate clumps and then, using supplemental ground data, arrive at density by knowing the average number of plants per clump. The data is derived simply by counting an entire frame or, more commonly, a subsample of a given area.

Condition and Trend

On any given range site the vegetation possesses a set of characteristics including a given species composition. This is referred to as the range condition. These sets of characteristics tend to change over time. These changes, their direction, magnitude and speed are referred to as range trend. Species composition, either changes in the relative proportion of species or changes in the occurrence of certain species, can be readily measured on large scale 70mm photographs (Lorain 1970; Tueller et al. 1972; Carneggie et al. 1971; Driscoll and Reppert 1968). Both long and short term changes can be measured. The adequacy of the permanent record becomes apparent in range condition and trend studies.

Large scale 70mm photography is useful for identifying and measuring litter, rocks, bare ground, other soil surface features (Carnegie and Reppert 1969; Driscoll and Reppert 1969; Carnegie et al. 1971; Lorain 1970). These factors are also very useful for assessing range condition and trend. In addition, accurate shrub measurements may be sufficient on many ranges to evaluate trend since their increase or decrease is highly correlated with changes in the herbaceous species. A reciprocal relationship has often been found. Fecal droppings can be counted or used as an index to range utilization.

Table 1. Ground and photo cover in percent in the Sonoran Desert near Casa Grande, Arizona and in the Mojave Desert near Mercury, Nevada.

	<u>Species</u>	<u>Ground</u>	<u>1:800</u>	<u>Aerial Photography</u> <u>R</u>	<u>1:2,000</u>
<u>Casa Grande</u>					
Palo Verde	<u>Cercidium sp.</u>	6.7	8.0	.80	8.7
Creosote Bush	<u>Larrea tridentata</u>	6.3	4.7	.81	
Giant Saguaro	<u>Carnegie gigantea</u>	.01	.05		trace
Ironwood	<u>Olneya tesota</u>	.12	.07	.77	trace
Bur Sage	<u>Ambrosia dumosa</u>	3.2	3.6	.74	
Mesquite	<u>Prosopis juliflora</u>	5.6	5.7	.89	
Whitethorn	<u>Acacia constricta</u>	7.2	8.2	.94	
<u>Mercury</u>					
Bur Sage	<u>Ambrosia dumosa</u>	8.0	2.5		
Joint fir	<u>Ephedra nevadensis</u>	1.8	1.5		
Range Ratany	<u>Krameria parvifolia</u>	3.4	4.8		
Creosote Bush	<u>Larrea tridentata</u>	4.4	4.4		
Lycium	<u>Lycium andersoni</u>	3.7	6.1		
	<u>Total</u>	<u>21.7</u>	<u>19.3</u>		

Table 2. Ground and photo derived density (plants/hectare) data at Casa Grande, Arizona and Mercury, Nevada.

<u>Species</u>	<u>Photo Density</u>		<u>Ground Density</u>
<u>Rock Valley</u>	Scale: 1:600		
<u>Ambrosia dumosa</u>	1403		2674
<u>Ephedra nevadensis</u>	496		651
<u>Krameria parviflora</u>	1092		1496
<u>Larrea tridentata</u>	829		891
<u>Lycium andersoni</u>	922		1233
<u>Casa Grande</u>	Scale: 1:800, 1:2,000		
<u>Cercidium sp.</u>	106	102	106
<u>Larrea tridentata</u>	76		177
<u>Carnegie gigantea</u>	4.5	4.1	4.5
<u>Olneya tesota</u>	0.4	0.4	0.4
<u>Ambrosia dumosa</u>	209		258

Plant Biomass

On many range sites plant biomass (above ground productivity) has been found to be highly correlated to plant cover and other parameters measurable on the aerial photographs. Spectrophotometric techniques (Tucker et al. 1975; Pearson et al. 1976) have application on short grass prairie range sites and other relatively homogeneous types. However, this latter

technique does not hold as much promise on heterogeneous shrub types where the correlation method holds greater promise. We approached this problem hopeful of finding easily measured characteristics on 70mm large scale stereo pairs that are highly correlated with range productivity. For example, we have recently found high correlations between shrub crown cover and productivity of grasses. Unfortunately, the measurements we have made do not yet extend to estimates of range utilization.

Plant Phenology

It has been widely stated that color infrared film has the capability of providing excellent data on plant vigor. This is only true to a certain extent. Mostly, the expectations are beyond the capability of the color infrared film. Vegetation maturation was followed weekly through an entire growing season in Hot Creek Valley, Nevada for a shrub type (Tueller and Swanson 1973). A color densitometric technique was unsuccessfully used to follow changes in plant vigor. Tone differences from date to date did not follow a prescribed pattern of changes even though many precautions were taken, mainly, all the film was purchased in a single batch from Kodak in Rochester and frozen until use, all photographs were taken at or near high noon and all processing was done in Kodak's Versamat processor under exacting conditions. The changes are thought to be a result of date and exposure differences and were most apparent in the tone recorded for the nonvegetation component.

However, relative vigor differences of a somewhat large magnitude can be easily assessed on the large scale color infrared film. With proper sampling techniques certain management problems related to plant vigor (e.g., range readiness, fire fuel estimates, and time for recreational use) may be solved or partially solved.

Erosion and Surface Soil Features

We have completed detailed work and developed specific procedures for using large scale 70mm color or color infrared stereo pairs to evaluate erosion features on rangelands. We have found it to be possible to duplicate Bureau of Land Management watershed evaluations directly from the stereo photography with greater ease and reliability than field efforts (Tueller and Booth 1975). Costs involved in flight time over the watershed, film and processing costs and labor for the evaluation were found to be less than \$0.02/ha (\$0.01/acre). Also, many off-road sites can be easily studied providing a very efficient sampling procedure. The criteria were changed somewhat to conform with information available from the stereo pairs, bare ground, vesicular crusts, litter, wind erosion, flow patterns, rills and gullies.

Other soil surface features such as cattle droppings and rodent disturbance for some species of small mammals can be easily evaluated and related to range utilization and condition and trend.

Vegetation Mapping

Vegetation maps depicting exact locations of ecotones between important range habitat types can be easily developed from large scale photographs. However, plant community or habitat type mapping is normally accomplished on smaller scale photographs. We have been working with 1:10,000 photography for this purpose and find it to be about optimum (Parkin 1977) although 4-inch to the mile (1:15,840) resource photography has great utility in this regard. The 1:10,000 scale frames were especially useful for differentiating shrub type from shrub type and for successfully differentiating topographic detail necessary for delineating certain habitat types.

Off-Road Vehicle Use

We have studied the effects of off-road vehicle use on several sites. At the Silver Bell (Tucson) IBP site photographs were taken before and after treatment with 4-wheel drive vehicles driving 40 km on approximately 51 hectares. Results showed only limited damage to vegetation (Table 3). Heavy damage was recorded from Bay Area motorcycles in the Pinoche Hills of the California Coast Range. The number, location, and relative depth of vehicle tracks can be easily evaluated.

Table 3. Density (plants/hectare) before and after off-road vehicle use in the Sonoran Desert near Tucson, Arizona obtained from 1:1500 scale 70mm color photography.

<u>Species</u>	<u>Before Treatment</u>	<u>After Treatement</u>
Palo Verde (<u>Cercidium</u> sp.)	21	15
Bur-sage (<u>Ambrosia dumosa</u>)	750	625
Ironwood (<u>Olneya tesota</u>)	4	4
Creosote Bush (<u>Larrea tridentata</u>)	180	130

Pinyon-juniper Chaining Evaluation

Age class distribution of the stand prior to treatment often determines the success of pinyon-juniper chaining, a control measure. Color IR film allows detailed investigation of this plus post-treatment evaluation of dead, damaged, and healthy trees of various sizes.

Environmental Impact

Numerous environmental impact applications are possible with the large scale 70mm format. These include vegetation inventories, plant damage assessment and measurements of accelerated erosion caused by various land use activities.

Vertical color aerial photographs were excellent for assessing damage to trees and shrubs. Mortality counts of single needle pinyon (Pinus monophylla) and Utah juniper (Juniperus osteosperma) on the Nevada Test Site (ERDA facility) on sequential color infrared photographs showed a sequential or residual increase in mortality (Tueller and Clark 1976). Total mortality could not be assessed until the growing season after detonation. This constitutes a unique example of many uses for environmental impact purposes.

Evaluating Herbicide Applications

Color infrared reflectiveness of a green rabbitbrush community has been used to determine optimum date for application of herbicides (Evans et al. 1973; Young et al. 1976). A single frame of 70mm film at a scale of 1:600 captures more than 250 green rabbitbrush plants and permits easy interpretation. When first a pink tinge is seen on rabbitbrush margins on CIR then there are only 2 weeks to the start of the optimum period for herbicide application.

Aquatic Vegetation

This imagery is excellent for marsh vegetation analysis, primarily due to the difficulty of ground access. The best time of year to photograph marsh vegetation was found to be late summer (Aug.-Sept.) when the submerged and floating plants were at a stage of maximum vegetative development. Keys were found to be especially useful for this application (Seher and Tueller 1973).

3. CONCLUSIONS

A large scale 70mm system is a simple, cost effective tool for obtaining range resources data over vast acreages. Exclusive ground sampling techniques have been biased by being restricted to sites along roads or navigable streams. Aerial sampling allows these biased samples to be expanded to objectively located sites on recognizable ecological habitat types far removed from roads. These techniques can now be used by range resource managers, although, for reasons hard to understand, primary emphasis continues on small scale, low resolution systems (e.g., Landsat II). Systematic use of supplementary large scale procedures, however, should be further tested and used in ongoing range management programs.

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ASSESSMENT OF FOREST PLANTATIONS
FROM LOW ALTITUDE AERIAL PHOTOGRAPHYHarold A. Nelson
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SUMMARY

Vertical color, and color-infrared, aerial photography obtained from altitudes between 183 m and 915 m provide a cost-effective method of determining tree survival and height growth in pine plantations on the North Carolina Coastal Plain. All interpretations were performed by professional forestry personnel from the original 70 mm. color transparencies.

Prompt assessment of tree survival is necessary if failed spots are to be successfully replanted. Counts of living trees made after the third growing season, and sometimes only two growing seasons after planting, are accurate enough to permit planning of replanting operations without extensive ground surveys.

Using a Bausch and Lomb Zoom 70 Stereoscope and a narrow-span Parallax Bar built by Charles A. Hulcher, Inc., tree heights were measured without cutting individual frames from the roll. Errors in relative orientation that resulted from this procedure were acceptable, and individual tree heights were determined within plus-or-minus 0.30 m of the corresponding ground measurement, approximately ninety percent of the time, when photographs were taken three or more growing seasons after planting.

Cost of photographic assessment of plantation survival and height growth is substantially lower than for traditional ground methods. The aerial vantage point also permits more complete sampling and evaluation of each plantation, with fewer omission errors, than when solely ground methods were used.

INTRODUCTION

Effective management of forest plantations requires substantial amounts of timely information relative to tree survival, stocking levels and tree heights. In the southeastern United States where forest plantations are grown on relatively short rotations of 20-25 years time is a critical economic consideration. Rapid changes resulting from forest management activities make photo coverage of total ownerships at medium photo scales, and at periodic intervals of four to five years, inadequate to meet the needs of intensive plantation management. Replanting of failures, establishing priorities for precommercial thinning, commercial thinning, fertilization, monitoring growth and predicting yields at rotation age all require current information. Early identification of site and stand problems is essential to their prompt correction.

In 1976 Weyerhaeuser Company examined the potential use of large scale vertical, color, aerial photography to obtain certain information needed for its High Yield Forest Program. Work was conducted in the coastal plains of eastern North Carolina where much of the forest land is characteristically flat, with high water tables, and where artificial drainage is a major pre-planting site treatment. Plantation failures are normally spotty segments within a whole plantation and are frequently associated with wetter areas.

STUDY OBJECTIVES

The primary objective of the study was to determine the capabilities of making tree counts in plantations two and three years after establishment. Priorities were placed on these ages because corrections, namely replanting, within these ages offer the greatest opportunities to maintain even-aged stands that can be managed and harvested as such; thus minimizing future management problems inherent with patchy age class distributions on the ground.

A second objective was to determine the capabilities of measuring tree heights in three year age classes. Tree heights are an important variable in growth and yield predictions.

METHODS

Vertical photography was obtained with a Hulcher Model 103 Sequence Camera with a 70 mm film format and equipped with a 152 mm focal length lens. Target photo scales for all studies was 1:1200. Variations in actual photo scales range from 1:1068 to 1:1224. Normal color reversal film, Kodak Emulsion 2448, was used in each study.

All interpretations were made from the originally exposed 70 mm film used with a Bausch and Lomb Zoom 70 Stereoscope mounted on a specially made light box and film transport system (Fig. 1.). Tree heights were determined from parallax measurements made with a narrow span parallax bar designed for use under the Zoom 70 Stereoscope without cutting film into separate frames (Figs. 2. and 3.).

Tree Counts

Tests to determine tree count reliabilities were conducted in two and three year old loblolly pine (*Pinus taeda*) plantations. A series of markers placed on the ground prior to photography were clearly visible in the photographs and were used as centers of circular photo plots 5 mm in diameter. These markers, 30.5 meters apart in the three year old plantation and 15.3 meters apart in the two year old plantation were also used to determine actual photo scale. Living pine trees detected in the photography were tallied and their locations indicated on a plot diagram. This was followed by an actual ground count on identical plots whose diameters were calculated from actual photo scale. Tree heights were also measured in the ground check. The photo interpreter was not present during the ground count. This procedure permitted comparisons of the photo counts with ground counts on an individual tree basis and provided a means of determining the source of error.

Tree Height Measurements

Tree heights were determined from stereo-parallax measurements of 183 trees in one three year old loblolly pine plantation. Trees had been planted 1.8 m apart on beds, ridges about 0.20 m higher than the ground level in the alleys between the beds. Beds, and hence tree rows, were 2.75 m apart and the alleys had been moved. Ground markers were used for location references and to calculate tree flying altitude. Again a diagram showing and numbering each tree presented a tree-by-tree comparison of true ground heights with photo measurements.

Four photo measurement trials were completed. Base readings were consistently made midway in the alleys between beds (tree rows), but at different frequencies from trial to trial.

Trial 1: One base reading was made for groups of four trees. About one half of the top readings were taken on the sunlit sides of the tree and about one-half on the partially shaded side. Measurements were made at 7X magnification.

Trial 2: One base reading was made for each tree. Top readings were consistently taken on the sunlit side of the tree top and magnification was increased to 10X.

- Trial 3: Similar to trial two except that one base reading was made for groups of seven to ten trees in a row.
- Trial 4: Similar to trials two and three except that one ground reading was made for groups of 35-50 trees in all directions around the point of the ground reading.

RESULTS

Tree counts made from large scale, vertical, color aerial photography identified 96 and 97 percent of the trees found in identical ground plots in two and three year old loblolly pine plantations, respectively. Omissions during photo counts were confined to the smaller trees under about one meter in height at the third year and under about one-half meter at the second year (Figs. 4. and 5.).

Tree height measurements from large scale color photography at three years age was consistently within 0.36 m of the actual ground mean. The largest errors were found in the first photo trial, and other trials gave essentially the same results with mean photo measurements being consistently within 0.16 m of actual mean height (Fig. 6.).

DISCUSSION AND CONCLUSIONS

The study results of both tree count and height measurement tests are within the accuracies required for operational purposes.

Tree Counts

Tree counts are considered well within the accuracies required. From a practical standpoint, trees missed in the photo count are considered insignificant; they will either die before rotation age is attained or will be suppressed trees contributing little volume to the mature stand.

Tree size per-se is not necessarily the only factor governing detection in photography. Numerous trees were identified that were smaller than several trees that were missed. A main factor is the relation of a tree to the surrounding grasses and herbaceous growth.

Photography for these studies was done during the dormant season when competing herbaceous growth was largely defoliated. The brush and dead grasses were still there however. Experience in similar plantations with similar photography during the summer growing season strongly suggests that this work need not be confined to the dormant season. In fact, photographing during the growing seasons could be advantageous in evaluating the competition and prescribing early treatment needs for its reduction.

Tree Heights

Tree height measurements were within the 10% of mean height accuracy required. While measurements in this study covered a total height range from 0.80 m to 2.5 m, only heights of dominant trees would be measured for operational purposes.

The bias towards higher photo height measurements than actual ground measurements was consistent and largely due to the fact that ground readings were taken from the photos midway in the alleys between the tree rows. Actual ground height measurements, however, were taken from the base of the trees at the tops of the beds. The beds were uniformly about 0.20 m higher than ground levels in the alleys. This difference in ground levels between alley bottoms and bed tops is slightly more than the indicated measurement error. Corrections for bed heights are easily made and when the correction is made, the mean tree heights measured from the photos is found to be slightly lower than the actual mean height (Table 1).

There was some tendency toward larger errors with the very smallest trees with photo measurements being less than actual tree heights. A likely reason for this is that many smaller trees have a pronounced single growth terminal which is not clearly resolved on film. Thus, top readings are likely to be made in a lower portion of the tree. In larger trees of the same age lateral branches grow upward forming some crown diameter nearer the tree top which is more clearly resolved on film. This point is not considered particularly significant because only dominant tree heights are measured for operational purposes.

Trials three and four were designed to more closely simulate actual situations where tree crowns frequently obscure much ground vision and good ground readings cannot be made for each tree measured. The results of these trials demonstrates that a ground reading is not necessary for each tree in relatively flat terrain when the photos are obtained with a 70 mm film format and a 152 mm lens.

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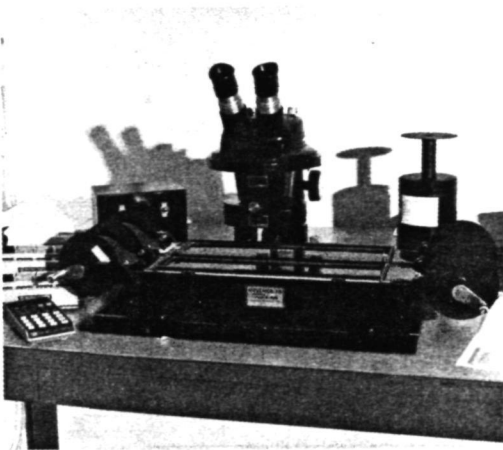


Figure 1. Illustrates the light box and film transport system used with the Bausch and Lomb Zoom 70 Stereoscope. The stereoscope is stationary, but the box has x and y travel to maintain stereo vision over the full stereo pair. The system carries two strips of film to accomodate films resulting from a dual camera system not discussed here. Total movement in the x direction is about 229 mm and spans both film strips in the y direction. Light intensities are variable for either film strip.



Figure 2. Illustrates the narrow span parallax bar designed for use under the Zoom 70 Stereoscope without cutting film into individual frames. The plates with dot marks protrude from both sides to permit measurements on either side or in the center of the film. The digital micrometer is used to facilitate reading and minimize reading errors. The error associated with imperfect alignment of the photos is accepted.



Figure 3. Shows the system in use. The small calculator is programmed to calculate tree heights.

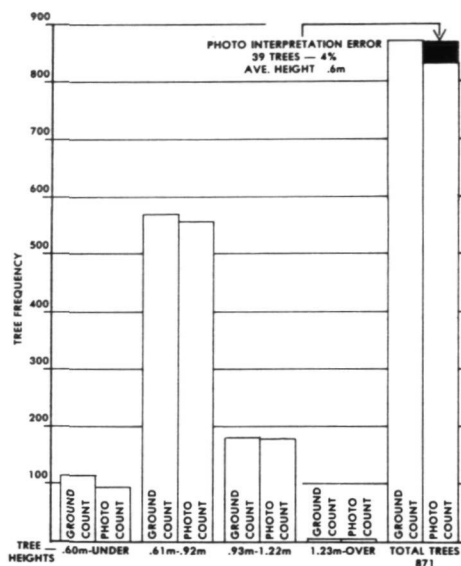


Fig. 4.

Comparison of actual tree counts with photo counts in two year old loblolly pine plantation.

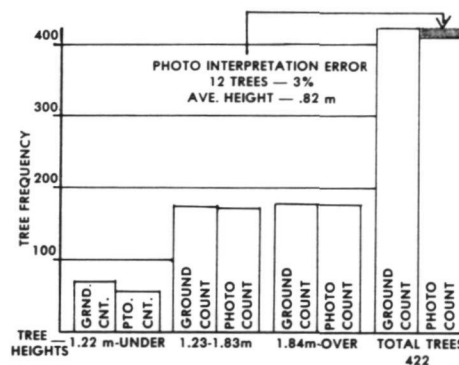


Fig. 5.

Comparison of actual tree counts with photo counts in three year old loblolly pine plantation.

	After second growing season	After third growing season
Photography		
Season	Dormant (March, 1976)	Dormant (Jan. 1976)
Film	Kodak 2448	Kodak 2448
Actual Scale	1:1224	1:1068
Ground cover	Tall grasses and weeds	Tall grasses and brush
Number Plots	40	25
Plot size (Circular	0.01 hectares	0.009 hectares

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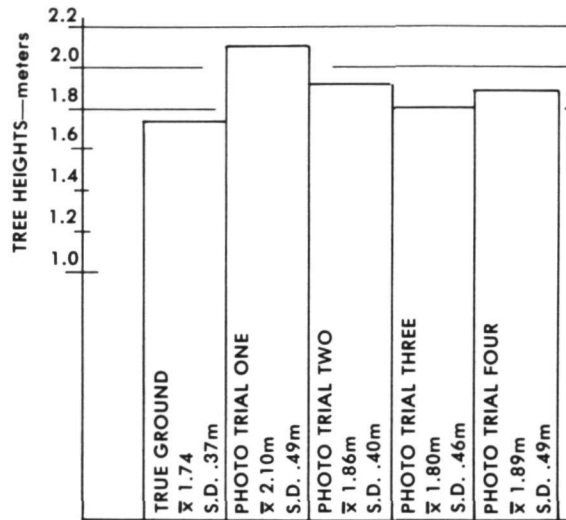


Fig. 6. A comparison of average actual ground height measurements with each of the four photo trials in a three year old loblolly pine plantation.

The increased accuracies in trials two, three, and four are attributed to increased interpretation experience and the increased magnification to 10X, which was maximum without loss of some resolution.

Photography - Dormant season - Nov. 1976
 Kodak 2448
 Actual photo scale 1:1140
 Flying altitude 174 m

	ALL TREES				DOMINANT TREES ONLY			
	<u>No. Trees</u>	<u>Avg. Ht. m</u>	<u>Corrected (-0.20 m)</u>	<u>Error m</u>	<u>No. Trees</u>	<u>Avg. Ht. m</u>	<u>Corrected (-0.20 m)</u>	<u>Error m</u>
Actual Ground	183	1.74			103	2.01		
Photo Trial One	183	2.10	1.90	+0.16(9%)	138	2.29	2.09	-0.08(4%)
Photo Trial Two	183	1.86	1.66	-0.08(5%)	117	2.10	1.90	-0.11(5%)
Photo Trial Three	183	1.80	1.60	-0.14(8%)	96	2.17	1.97	-0.04(2%)
Photo Trial Four	183	1.89	1.69	-0.05(3%)	107	2.23	2.03	+0.02(1%)

Table 1. Comparisons of true ground mean heights with mean heights from each of the photo measurements for all trees and for dominant trees only (trees 1.74 m in height and over). The correction deducts 0.20 mm from photo results to remove the differences due to bed heights referred to in the text.

PERFORMANCE TESTS OF SIGNATURE EXTENSION ALGORITHMS

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ABSTRACT

Comparative tests were performed on seven signature extension algorithms to evaluate their effectiveness in correcting for changes in atmospheric haze and Sun angle in a Landsat scene. Four of the algorithms were cluster matching, and two were maximum likelihood algorithms. The seventh algorithm determined the haze level in both training and recognition segments and used a set of tables calculated from an atmospheric model to determine the affine transformation that corrects the training signatures for changes in Sun angle and haze level. Three of the algorithms were tested on a simulated data set, and all of the algorithms were tested on consecutive-day data. The classification performance on the data sets using the algorithms is presented, along with results of statistical tests on the accuracy and proportion estimates. The three algorithms tested on the simulated data produced significant improvements over the results obtained using untransformed signatures. For the consecutive-day data, the tested algorithms produced improvements in most but not all cases. The tests indicated also that no statistically significant differences were noted among the algorithms.

1. INTRODUCTION

Signature extension is the process of using signatures from a given segment[†] (the training segment, or T-SEG) to classify another segment (the recognition segment, or R-SEG). If such a procedure gave classification accuracies and proportions that were comparable to those obtained with local training, it would save much time and effort in a project such as the Large Area Crop Inventory Experiment (LACIE), where many segments must be classified. The simplest approach is to use the untransformed (UT) signatures from the T-SEG. Generally, this does not work well because these signatures are different from the signatures in the R-SEG as a result of differences in haze level, Sun angle, and various factors which affect target reflectance, such as soil color and growth stage.

In this study, comparative tests were performed on seven signature extension algorithms to evaluate their effectiveness in correcting for changes in atmospheric haze and Sun angle in a Landsat scene. The evaluation criteria were classification accuracy and proportion estimation. The algorithms tested were the Maximum Likelihood Estimation of Signature Transformation (MLEST), the University of Houston Maximum Likelihood Estimator (UHMLE), the Optimal Signature Correction Algorithmic Routine (OSCAR), modified OSCAR (MOD OSCAR), the Rank Order Optimal Signature Transformation Estimation Routine (ROOSTER), modified ROOSTER (MOD R), and the Atmospheric Correction (ATCOR) program.

*Under National Aeronautics and Space Administration Contract NAS 9-15200 at the Lyndon B. Johnson Space Center, Houston, Texas.

[†]A segment in this paper is a 9-by-11-kilometer ground area.

2. THE DATA SETS

Two data sets were used — one consisting of simulated data (section 2.1) and the other a set of acquisitions on consecutive days (section 2.2). The simulated data provided for a controlled experiment in which the transformations were known and in which the problems of nonnormal distributions and nonrepresentative statistics were avoided. The consecutive-day data set provided for a test of the capability of the algorithms to correct for atmospheric effects when effects caused by differences in the training and recognition targets are eliminated. The algorithms ROOSTER, UHMLE, and MLEST were tested on the simulated data. All the algorithms were tested on the consecutive-day data set.

2.1 SIMULATED DATA

The 1975 data base of the Earth Resources Interactive Processing System (ERIPS) contains four passes of four-channel simulated data for each of segments 429 and 432. Each segment has 117 lines and each line 196 pixels. The field coordinates reside in the ERIPS field data base. Four classes exist within each segment: wheat (W), barley (B), stubble (S), and grass (G). Each class is divided into two subclasses.

The data were generated from means and covariance matrices determined from training fields in Hill County, Montana. An algorithm was used to generate multivariate normal data with the same statistics. This was done separately for the four passes of segment 429. Each pass of segment 432 was created from the distributions used in the corresponding pass of segment 429 by transforming them with an affine transformation so that the data corresponded to a different Sun angle. Segment 429 was chosen to be the T-SEG and segment 432 the R-SEG. All classifications were made in four channels. Four data sets correspond to the four passes: SIM1, SIM2, SIM3, and SIM4.

2.2 CONSECUTIVE-DAY DATA

Seven sets of consecutive-day passes of Landsat-1 data from intensive test sites in Ellis, Finney, and Saline Counties, Kansas, were tested. The first set is denoted F1709-8. (The F indicates Finney County; 1709-8 indicates the dates of the training and recognition passes, respectively; i.e., the training pass was made 1709 days and the recognition pass 1708 days after the launch of Landsat-1.) In all, four sets from the Finney, two from the Saline, and one from the Ellis County test sites were used.

Ground truth was available for all fields in all test sites. A subset was selected for training fields, and fields were grouped into subclasses with the aid of cluster maps. In general, the rectangular ground-truth areas were not oriented so that their sides were parallel to the scan lines in the Landsat-1 data. To facilitate the application of the various algorithms, a "signature extension area" was defined (the smallest rectangular area with sides parallel to the Landsat scan lines) that included the ground-truth area in each case. For Finney County, this included the entire 9- by 11-kilometer segment (117 lines, 196 pixels) containing the ground-truth area. For Saline County, it included lines 26 to 91 and pixels 27 to 146; for Ellis, it included lines 24 to 109 and pixels 49 to 144.

3. APPROACH

The overall approach was to make signature extension runs using these algorithms and to compare the results with local classification results or ground truth. The algorithms were to provide modified training statistics which then were used to classify the recognition area. The UHMLE computes these modified statistics directly; all the other algorithms compute an affine transformation which is then used to modify the training statistics.

3.1 THE ALGORITHMS

The descriptions given here provide only a very rough idea of how these algorithms work. References are given to more detailed discussions. In the case of the consecutive-day data, the algorithms were usually run using the data from the signature extension area defined above. Exceptions will be noted.

3.1.1 MLEST. The MLEST technique [1] uses an iterative gradient optimization procedure (the Davidon-Fletcher-Powell algorithm) to obtain maximum likelihood estimates for the affine transformation assumed to relate the training and recognition statistics. The training subclass *a priori* probabilities and statistics are input

to the program, which outputs the maximum likelihood estimate of the affine transformation.

3.1.2 UHMLE. The UHMLE [2] takes subclass statistics from a T-SEG and image data from an R-SEG and computes maximum likelihood estimates of subclass proportions and statistics for the R-SEG. Two versions of UHMLE were used. The first, UH all, uses the ground-truth area as input data; when this version is used to obtain maximum likelihood estimates of proportions generated internally by UHMLE, it is referred to as UH all MLE. The second, UH fields, uses only the training fields within the R-SEG; when this version is used to obtain maximum likelihood estimates of proportions generated internally by UHMLE, it is referred to as UH fields MLE. The second version was introduced to eliminate the effect of insufficient training. The statistics generated by UHMLE are used to classify the ground-truth area in the R-SEG.

3.1.3 OSCAR. The OSCAR [3] considers every possible transformation defined by four cluster means: two in the T-SEG and two in the R-SEG. From these transformations, the algorithm selects those that are "best" able to match the training clusters with the recognition clusters. The amount of computation is kept to a manageable level (1) by rejecting pairings judged to be unreasonable on the basis of rankings and (2) by testing the remaining transformations, using each to transform all the training clusters, and calculating a measure based on the distance of the transformed training clusters from the recognition clusters. The five transformations giving the "best" measure are then averaged.

3.1.4 MODIFIED OSCAR. The MOD OSCAR [4], in effect, defines a transformation for each pair of clusters - one in the R-SEG and one in the T-SEG. Each cluster is used with its projection onto the soil line¹ to define a transformation. The transformations are evaluated as in OSCAR, and the best transformation is output.

3.1.5 ROOSTER. To perform signature extension with ROOSTER [5], one first obtains a set of class means for the T- and R-SEG's. These class means, called mean vectors, are obtained by clustering or by deriving class statistics from training fields.

The first step is to derive rank vectors corresponding to each of the mean vectors. These rank vectors are obtained by computing for each channel the rank of each mean relative to the others for that segment. The rank vectors are used to match the classes (or clusters) in the training area with those in the recognition area. Then, a regression analysis is used to determine the affine transformation which best transforms the mean vectors from the training area into the corresponding mean vectors from the recognition area.

In this study, the ROOSTER was used in three different ways: The first, R(C), consisted of using clusters to define the class means for both segments; the second, R(S), used subclass means derived from training fields for both segments (It is expected to provide an estimate of how well ROOSTER would do if an ideal clustering algorithm were available.); and the third, R(S/C), used subclass statistics for the T-SEG and clusters for the R-SEG. This is an alternate way of using ROOSTER operationally, since subclass statistics are always available for the training area.

3.1.6 MODIFIED ROOSTER. The MOD R [4] is identical to ROOSTER except that the regression line is computed with the cluster means and the projections of the cluster means onto the soil line.

3.1.7 ATCOR. The ATCOR program [6] is designed to correct for differences in haze level and Sun angle between the training and recognition data sets. The program processes each of these data sets separately. In each case, the input is the Landsat-1 data and the solar zenith angle. The ATCOR program determines the haze level from the brightness of certain dark targets in the scene and uses an atmospheric model to calculate a set of coefficients relating the Landsat data for that scene to the reflectance of the targets on the ground. The coefficients obtained from the training and recognition data sets are then used to compute the affine transformation to be applied to the training data.

¹The soil line is the "bottom of the tasselled cap" or that part of channel space containing bare soil.

3.1.8 REGRES. Rather than a signature extension algorithm, the REGRES program is a method for finding the optimum affine transformation to be applied to the statistics of the consecutive-day data. In each channel, a scatter plot is made of the second-day data versus the first-day data. A straight line is then fitted to the data which minimizes, in the least squares sense, the perpendicular distance from the points to the line. In principle, this line represents the best affine transformation for the training statistics.

3.2 CLASSIFICATION AND EVALUATION

After obtaining the modified statistics, we used standard LACIE classification procedures and the Laboratory for Applications of Remote Sensing System (LARSYS) implemented on the Univac 1108 computer to classify the R-SEG's. A two-class classifier was used with equal *a priori* probabilities for wheat and nonwheat. Within each class, the subclasses had equal *a priori* probabilities. A 1-percent chi-squared threshold was used. For the simulated data, entire areas were classified; for the consecutive-day data, the ground-truth areas were classified.

3.2.1 CLASSIFICATION ACCURACY. The classification accuracy was determined for wheat and nonwheat by using the training fields defined in section 2 as test fields. From these, the overall accuracy was computed. This is given by:

$$\text{Overall accuracy} = q_w p(w/w) + q_\phi p(\phi/\phi) \quad (1)$$

where $p(w/w)$ = wheat accuracy, $p(\phi/\phi)$ = nonwheat accuracy, q_w = wheat proportion in ground-truth area, and q_ϕ = nonwheat proportion in ground-truth area. The proportions q_w and q_ϕ were known from ground truth. The wheat, nonwheat, and overall accuracies were compared with the results obtained from local classification (section 4).

3.2.2 WHEAT PROPORTIONS. The classification results yielded wheat proportions for the ground-truth areas defined in section 2. In addition, the UHMLE program yielded a maximum likelihood estimate of the wheat proportions. These results were compared with the ground-truth proportions and the results obtained from local classification.

4. RESULTS

The results of this processing are given in tables 1 to 11. Table 1 gives the A and B coefficients determined for the consecutive-day data by those algorithms which produce an affine transformation. The algorithms are listed in the order in which they performed in the accuracy test.

Based on numerical calculations using an atmospheric model [6], certain constraints are expected to apply to the A and B coefficients corresponding to a change in the haze level. These should apply to the consecutive-day data if the haze levels present are uniform. Among these constraints, which apply to all channels, are the following:

1. If there is no difference in haze level between the T-SEG and the R-SEG, $A = 1.0$ and $B = 0.0$.
2. If the T-SEG has more haze than the R-SEG, $A > 1.0$ and $B < 0.0$.
3. If the T-SEG has less haze than the R-SEG, $A < 1.0$ and $B > 0.0$.

In many cases, the data in table 1 do not obey these rules. Examples can be found in the following anomalies:

1. $A > 1.0$ for some channels and $A < 1.0$ for others; e.g., R(S) for F1655-4.
2. $A > 1.0$ and $B > 0.0$; e.g., MLEST for F1673-2.
3. $A < 1.0$ and $B < 0.0$; e.g., R(C) for F1726-7, channel 2.

These failures to obey the constraints probably are due in part to nonuniform haze levels in the data and to changes in the look angle.

Tables 2, 3, 4, and 5 give the accuracy results for wheat and nonwheat using both data sets. The accuracy obtained with signature extension is expressed as a percentage difference from the local result; i.e.,

$$\text{Percentage difference} = \frac{\text{signature extension accuracy} - \text{local accuracy}}{\text{local accuracy}} \times 100\% \quad (2)$$

Tables 6 and 7 give similar results for overall accuracy.

Tables 8 to 11 give the differences for both data sets (1) between results obtained using signature extension and local classification and (2) between results obtained using signature extension and ground truth. The means and standard deviations were obtained using the absolute values of the numbers in the tables.

5. ANALYSIS

In this section, a statistical analysis is performed on the data in tables 6 and 10. Data for the UHMLE algorithm were not included because of their large variances.

First, an analysis of variance was performed on the data in table 6. The purpose of an analysis of variance is to separate a response variable into component parts. In this way, the test for a particular factor will become more sensitive because variations due to other causes have been removed. In this experiment, two factors were present: signature extension algorithms and the seven consecutive-day acquisitions. The second factor could have been grouped several different ways, on the bases of days, sites, and presence of haze.

The last alternative was chosen. Each pass was classified as either clear or hazy by visually inspecting the images of the data produced by ERIPS. The results are shown in table 12. Three T-SEG-R-SEG combinations occurred; namely, haze-clear, clear-haze, and clear-clear. It was assumed that each combination would produce different results (classifications), thus the need for this factor in the analysis.

The interaction between the algorithms and haze combinations (A×H) was also expected to be present; that is, one algorithm might have performed well for the clear-haze consecutive-day acquisitions and poorly for the haze-clear days, whereas the opposite results might have occurred for another algorithm.

The model for the experiment was

$$y_{ijk} = \mu + a_i + h_j + ah_{ij} + e_{ijk} \quad (3)$$

where μ = overall mean, a_i = contribution of the i th algorithm, h_j = contribution of the j th haze level, ah_{ij} = contribution of algorithm i and haze level j to the interaction, e_{ijk} = error term for the k th observation for the i th algorithm and the j th haze level, and y_{ijk} = response variable. In the analysis of variance for overall accuracy, y_{ijk} = percentage accuracy difference; that is, the quantity given in table 6.

The results of this analysis of variance are given in table 13, where significant differences between the algorithms and between the haze conditions are apparent.

Table 14 gives the average accuracy difference over the algorithms for each haze condition. Because the analysis of variance indicated significant differences between haze conditions, we can infer from table 14 that the presence of haze over the T-SEG is significantly different from the other two conditions.

The results for the different haze conditions were plotted as a function of the algorithms (fig. 1). The condition with haze over the T-SEG shows consistently better results than the other two conditions. A similar analysis was performed for the wheat proportions. In this case, y_{ijk} was the quantity given in table 10. R(S/C) was not included because of its large variance. The results show a significant difference between the haze conditions but not between the algorithms (table 15). Table 16 gives the average proportion difference over the algorithms for each haze condition, and figure 2 shows the performance of each algorithm for each of the three haze conditions. Here again, the haze-clear condition seems to give the best results.

6. CONCLUSIONS

The results of these tests are summarized in table 17. The first two columns list the algorithms in the order in which they performed on the accuracy test for the simulated and consecutive-day data. The numbers given are the mean percentage differences between the accuracy obtained using the algorithms and local accuracy (see tables 6 and 7). The minus signs indicate that the algorithm was less accurate than local classification. A statistical analysis was performed on the accuracy results for the consecutive-day data with the exception of data for the three versions of UHMLE (which were omitted because of large variances). The analysis indicated (1) no significant differences among the algorithms and (2) that the results obtained when the T-SEG appeared hazier than the R-SEG were better than in the other two conditions observed; i.e., when both were clear or the R-SEG was hazier.

The comparison of wheat proportion differences (between ground truth and local results) in the last four columns of table 17 shows the performance order of the algorithms to be the same for simulated data but quite different for consecutive-day data. This was because local results were quite different from ground-truth results for the consecutive-day data. These four columns of numbers are the means of the absolute values of the differences as given in tables 8, 9, 10, and 11. A statistical analysis was performed on the consecutive-day data for wheat proportion differences from local results. Data from R(S/C) and the three versions of UHMLE were not used because of large variances. The results given in table 15 indicate no significant differences among the algorithms tested. Here again, the best results were obtained when the T-SEG appeared hazier than the R-SEG.

Finally, it must be mentioned that, because of time limitations, this test was performed using the currently available algorithms. Subsequently, it has been discovered that some of the algorithms show better performance when later versions are used. For example, the program UHMLE has a later version that begins with the transformation $(x + b)$ before estimating the R-SEG statistics. However, the results presented in this paper provide illustrative information which can be used in solving the signature extension problem.

7. REFERENCES

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TABLE 1. A AND B COEFFICIENTS FOR CONSECUTIVE-DAY DATA

Data	R(S)		MLEST		OSCAR		REGRES		MOD R		R(C)		MOD OSCAR		ATCOR		R(S/C)	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
F1709-8	1.20	-7.1	1.06	-2.32	1.12	-4.4	1.24	-9.1	1.03	-0.9	1.12	-5.1	1.06	-2.6	1.12	-6.6	1.05	-3.6
	1.18	-5.4	1.02	-0.9	1.08	-3.0	1.14	-5.2	1.04	-1.7	1.09	-4.5	1.05	-2.6	1.10	-5.4	0.99	-3.2
	0.99	2.2	1.05	-1.4	1.01	1.1	1.15	-6.6	1.03	0.1	1.03	0.5	1.05	-1.8	1.08	-5.8	1.23	-10.5
	0.99	1.3	1.06	-0.7	0.98	1.5	1.12	-2.1	1.03	0.3	1.02	0.9	1.05	-0.8	1.07	-2.3	1.23	-4.2
F1673-2	0.98	0.1	1.05	0.1	0.84	4.5	0.78	5.2	0.94	1.0	0.84		0.89	3.4	0.95	2.8	0.99	0.2
	0.99	-0.9	1.06	0.0	0.90	1.8	0.82	2.4	0.94	0.3	0.88	1.5	0.98	0.5	0.96	2.4	1.01	-0.7
	1.15	-8.6	1.10	0.6	1.10	-8.8	1.3	-17.6	0.98	-1.2	1.04	-5.6	0.95	1.6	0.96	2.4	1.13	-6.3
	1.16	-5.2	1.19	0.8	1.06	-3.3	1.5	-13.3	1.00	-0.8	1.06	-3.3	0.94	1.6	0.97	1.0	1.16	-4.0
F1655-4	1.06	-0.1	1.36	-8.9	1.04	-0.1	1.05	-0.2	1.05	-0.2	1.00	1.6	1.07	-1.0	0.92	4.7	1.30	-8.1
	1.08	-0.1	1.24	-2.3	1.03	0.5	1.04	1.0	1.06	0.0	1.00	1.7	1.03	0.6	0.94	4.3	1.26	-5.9
	0.92	6.5	1.12	-0.8	0.98	3.1	0.93	5.5	1.02	0.8	0.81	12.1	1.04	-0.8	0.94	3.8	1.22	-6.2
	0.95	2.2	1.35	-5.5	1.00	0.9	1.05	0.2	1.03	0.3	0.89	3.9	1.04	-0.6	0.95	1.4	1.16	-1.7
F1726-7	0.91	0.0	0.94	-1.6	0.80	0.3	0.92	-0.9	0.88	0.4	0.89	0.1	0.86	2.0	0.94	3.3	1.00	-3.6
	0.93	-0.6	0.99	-3.5	0.81	0.5	0.94	-1.2	0.89	0.6	0.91	-0.8	0.88	1.9	0.95	2.8	1.07	-6.1
	0.91	0.6	1.22	-14.8	1.02	-6.0	1.06	-8.6	0.90	0.2	1.03	-6.4	0.87	2.1	0.96	2.5	1.33	-18.7
	0.95	-0.6	1.17	-5.5		0.5	0.98	-1.6	0.91	-0.3	0.80	3.8	0.87	1.3	0.97	0.9	1.17	-3.9
S1455-4	1.22	-4.9	0.98	0.4	0.89	2.1	0.94	1.0	0.91	1.3	0.88	2.2	0.91	2.1	0.98	0.8	2.12	-25.3
	1.18	-3.9	0.98	0.1	0.93	0.6	1.13	-3.0	0.92	0.6	0.90	1.2	0.92	1.5	0.98	0.6	1.58	-11.7
	1.08	-1.9	1.02	0.0	0.92	1.1	0.99	-0.2	0.97	-1.3	1.00	-2.3	0.92	1.2	0.98	0.5	1.33	-7.0
	1.14	-1.4	0.97	0.5	0.91	0.6	0.98	-0.2	0.96	-0.8	0.98	-1.3	0.92	0.3	1.00	0.2	1.32	-3.5
S1725-4	0.95	3.5	0.99	1.7	1.01	1.2	1.01	1.4	1.05	-0.3	0.80	8.5	1.00	1.1	0.94	3.3	1.19	-4.9
	0.98	2.9	1.03	0.7	1.01	1.3	1.04	0.9	1.06	-1.0	0.81	8.1	1.06	-0.7	0.95	2.8	1.22	-5.5
	0.97	3.4	1.04	1.2	1.01	2.2	1.02	1.8	1.04	-0.3	0.98	2.9	1.04	0.1	0.96	2.5	1.31	-4.4
	1.02	0.5	1.04	0.6	1.00	1.1	1.00	1.0	1.05	-0.6	0.96	1.5	1.03	0.2	0.97	0.9	1.32	-1.7
E1726-5	1.06	-0.5	1.03	0.1	0.99	2.1	1.04	0.6	0.96	3.5	0.95	3.7	0.96	2.6	0.92	4.7	1.20	-6.4
	1.06	-0.3	1.02	0.0	0.94	4.4	1.00	2.3	0.95	4.4	0.93	4.8	1.06	-1.5	0.94	4.3	1.17	-5.9
	1.03	0.3	1.01	0.0	0.99	3.0	0.97	3.7	0.98	3.1	0.99	2.9	1.03	-0.6	0.94	3.8	1.13	-4.2
	1.08	-0.7	1.02	0.0	1.01	1.0	1.01	1.0	1.01	1.2	1.01	1.1	1.02	0.5	0.95	1.4	1.15	-2.0

TABLE 2. WHEAT ACCURACY FOR
SIMULATED DATA*

Data	Local	Percentage difference between local accuracy and that obtained with various algorithms				
		R(S)	MLEST	UH fields	R(C)	UT
SIM1	84.4	-2.0	6.3	-100	-28.4	-100
SIM2	97.1	0.0	1.2	-2.9	0.0	-26.3
SIM3	94.8	0.2	3.5	2.8	-12.8	-84.4
SIM4	87.9	-0.1	6.5	-13.5	-1.7	-28.0
Mean	91.1	-0.5	4.4	-28.4	-10.7	-59.7
Std. dev.	5.9	1.0	2.5	48.2	13.1	38.1

TABLE 3. NONWHEAT ACCURACY FOR
SIMULATED DATA*

Data	Local	Percentage difference between local accuracy and that obtained with various algorithms				
		R(S)	MLEST	UH fields	R(C)	UT
SIM1	96.4	0.5	-6.3	-0.2	-30.0	-99.1
SIM2	99.1	0.0	-0.5	-0.1	0.0	-15.8
SIM3	97.7	0.0	-1.1	-2.3	-2.9	-39.5
SIM4	94.3	-0.1	-6.0	-2.4	-3.2	-3.2
Mean	96.9	0.1	-3.5	-1.3	-9.0	-39.4
Std. dev.	2.0	0.3	3.1	1.3	14.1	42.5

TABLE 4. WHEAT ACCURACY FOR CONSECUTIVE-DAY DATA*

Data	Local	Percentage difference between local accuracy and that obtained with various algorithms											
		R(S)	MLEST	OSCAR	REGRES	MOD R	R(C)	MOD OSCAR	ATCOR	UH fields	UT	R(S/C)	UH all
F1709-8	96.7	0.5	1.1	0.7	1.2	0.7	1.1	1.3	1.2	-15.6	1.1	2.0	-21.9
F1673-2	97.3	-0.8	0.9	-3.9	-6.6	-2.6	-3.8	-2.9	-2.9	-3.9	-0.6	0.2	-2.2
F1655-4	93.5	-15.5	2.7	-12.8	-11.1	-12.7	-17.8	-14.5	-19.3	-9.6	-17.8	-1.8	-49.4
F1726-7	82.6	-3.3	-6.7	-2.3	-3.0	-5.9	-10.9	-1.9	-1.1	-27.4	-2.4	-8.4	-6.4
S1455-4	92.0	1.0	1.6	-4.0	-2.7	-7.1	-11.7	-6.1	-0.7	-16.8	0.0	-2.1	-42.6
S1725-4	79.7	7.3	2.0	4.6	7.0	-0.9	8.8	1.8	-0.6	1.8	-20.2	-13.6	21.3
E1726-5	92.6	-1.9	1.1	-0.3	-2.3	-1.5	0.4	-0.4	-6.2	-50.9	-1.0	3.6	-49.2
Mean	90.6	0.1	0.4	-2.6	-2.5	-4.3	-4.8	-3.2	-4.2	-17.5	-6.8	-5.2	-21.5
Std. dev.	6.8	3.5	3.2	5.4	5.7	4.6	9.1	5.6	7.0	17.5	9.5	8.3	27.2

*A minus sign means the algorithm was less accurate than local classification.

TABLE 5. NONWHEAT ACCURACY FOR CONSECUTIVE-DAY DATA*

Data	Local	Percentage difference between local accuracy and that obtained with various algorithms											
		R(S)	MLEST	OSCAR	REGRES	MOD R	R(C)	MOD OSCAR	ATCOR	UH fields	UT	R(S/C)	UH all
F1709-8	73.9	-8.5	-6.8	-10.3	-10.6	-11.2	-12.0	-11.5	-12.4	10.7	-12.0	-18.7	19.9
F1673-2	95.7	-2.3	-1.0	-3.0	-11.5	1.6	-0.9	0.1	-5.7	-27.2	0.3	-2.3	-30.8
F1655-4	95.4	0.4	-3.4	1.4	0.7	0.4	-0.5	0.6	1.4	-0.9	0.6	-4.4	-4.0
F1726-7	79.1	3.7	3.9	5.8	7.6	-0.4	2.3	3.9	-7.5	10.6	-10.5	-6.6	-6.8
S1455-4	78.9	-2.3	-5.1	-2.8	-0.5	3.0	7.6	3.0	1.3	-4.6	0.0	-5.8	-8.0
S1725-4	93.5	-6.5	-3.5	-7.7	-8.4	-6.1	-14.7	-5.7	-9.7	-11.8	-7.0	-8.1	-23.5
E1726-5	45.2	-5.1	-17.3	-9.3	-5.3	-2.2	-11.1	-25.2	3.1	86.1	-28.5	-31.4	61.3
Mean	80.2	-2.9	-2.2	-3.7	-4.0	-2.1	-4.2	-5.0	-4.2	9.0	-9.5	-11.0	1.2
Std. dev.	17.9	4.2	12.4	5.9	6.9	5.0	8.4	10.4	6.1	36.5	10.7	10.4	31.0

TABLE 6. OVERALL ACCURACY FOR CONSECUTIVE-DAY DATA*

Data	Local	Percentage difference between local accuracy and that obtained with various algorithms											
		R(S)	MLEST	OSCAR	REGRES	MOD R	R(C)	MOD OSCAR	ATCOR	UH fields	UT	R(S/C)	UH all
F1709-8	79.5	-5.8	-4.4	-7.0	-7.1	-7.6	-8.1	-7.8	-8.5	2.7	-8.2	-12.5	7.3
F1673-2	96.1	-2.0	-0.5	-3.2	-10.2	0.5	-1.7	-0.7	-5.0	-21.3	0.1	-1.7	-23.7
F1655-4	94.9	-3.3	-1.8	-2.1	-2.1	-2.7	-4.7	-3.0	-3.6	-3.1	-3.8	-3.8	-15.0
F1726-7	80.0	1.9	1.7	3.8	4.9	-1.9	-1.1	2.4	-5.9	0.9	-8.5	-7.1	-6.8
S1455-4	86.5	-0.2	-0.9	-3.5	-1.8	-3.2	-4.4	-2.5	0.1	-12.1	0.0	-3.5	-29.5
S1725-4	85.4	1.1	-0.5	-0.9	0.0	-3.2	-1.9	-5.0	-4.7	-4.3	-14.1	-11.0	0.9
E1726-5	66.2	-3.2	-6.0	-3.8	-3.5	-1.8	-4.1	-9.8	-2.7	1.4	-11.5	-9.8	-7.3
Mean	84.1	-1.6	-1.8	-2.4	-2.8	-2.8	-3.7	-3.8	-4.3	-5.1	-6.6	-7.1	-10.6
Std. dev.	10.2	2.7	2.6	3.3	4.9	2.5	2.4	4.2	2.7	8.7	5.5	4.2	13.1

TABLE 7. OVERALL ACCURACY FOR SIMULATED DATA*

Data	Local	Percentage difference between local accuracy and that obtained with various algorithms				
		R(S)	MLEST	UH fields	R(C)	UT
SIM1	93.5	0.0	-3.5	-21.7	-29.6	-99.3
SIM2	98.6	0.0	0.0	-0.7	0.0	-18.3
SIM3	97.0	0.1	0.0	-1.0	-5.2	-50.0
SIM4	92.8	-0.1	-3.2	-5.0	-2.9	-8.8
Mean	95.5	0.0	-1.7	-7.1	-9.4	-44.1
Std. dev.	2.8	0.1	1.9	9.9	13.6	40.8

TABLE 8. WHEAT PROPORTIONS FOR SIMULATED DATA AS DETERMINED USING LOCAL RESULTS

Data	Local	Signature extension proportion minus local proportion					
		R(S)	R(C)	MLEST	UH fields MLE	UH fields	UT
SIM1	24.3	-0.5	-1.9	0.6	-16.8	-22.3	-24.3
SIM2	24.7	0.0	0.0	0.6	-1.0	-1.1	-3.2
SIM3	24.9	0.1	-3.1	1.5	1.7	1.6	-20.0
SIM4	24.2	0.0	-0.2	6.8	-0.3	-0.6	-6.3
Mean absolute values		0.2	1.3	2.4	5.0	6.4	13.5
Std. dev.		0.2	1.5	3.0	7.9	10.6	10.3

TABLE 9. WHEAT PROPORTIONS FOR SIMULATED DATA AS DETERMINED USING GROUND TRUTH

Data	Ground truth	Signature extension proportion minus ground-truth proportion					
		R(S)	R(C)	MLEST	UH fields MLE	UH fields	UT
SIM1	23.9	-0.1	-1.5	1.0	-16.4	-21.9	-23.9
SIM2	23.9	0.8	0.8	1.4	-0.2	-0.3	-2.4
SIM3	23.9	1.1	-2.1	2.5	2.7	2.6	-19.0
SIM4	23.9	0.3	0.1	7.1	-0.3	-0.3	-6.0
Mean absolute values		0.8	1.1	3.0	4.9	6.3	12.8
Std. dev.		0.4	0.9	2.8	7.8	10.5	10.3

*A minus sign means the algorithm was less accurate than local classification.

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**TABLE 10. WHEAT PROPORTIONS FOR CONSECUTIVE-DAY DATA
AS DETERMINED USING LOCAL RESULTS**

Acquisition	Local	Signature extension proportion minus local proportion											
		R(S)	REGRES	OSCAR	MOD R	UT	MLEST	ATCOR	MOD OSCAR	R(S/C)	R(C)	UH all	UH fields
F1709-8	35.4	5.9	7.5	9.0	9.4	9.8	7.8	10.7	10.3	16.5	10.3	-8.9	-8.5
F1673-2	28.9	3.1	-2.0	0.6	-2.0	1.9	5.0	-1.6	-1.9	4.4	-1.5	20.7	13.3
F1655-4	27.7	-2.2	-2.2	-2.1	-1.6	-4.7	3.9	-4.9	-2.8	2.8	-3.8	1.6	4.6
F1726-7	28.8	-1.0	-2.0	-1.4	-1.4	3.1	-0.4	2.6	-1.4	1.9	-2.6	-2.4	-13.7
S1455-4	53.7	0.5	-3.3	-3.5	-8.6	-2.0	4.8	-3.0	-7.6	-0.3	-13.3	-11.4	-10.6
S1725-4	35.3	4.6	5.0	5.3	2.9	-0.8	2.6	4.4	3.6	-0.9	9.6	19.6	5.5
E1726-5	61.9	1.8	1.4	3.3	0.9	6.6	4.9	-3.2	6.0	9.8	3.6	-25.1	-36.1
Mean absolute values		2.7	3.3	3.6	3.8	4.1	4.2	4.3	4.8	5.2	6.4	12.8	13.2
Std. dev.		1.9	2.2	2.9	3.6	3.2	2.3	3.0	3.3	5.9	4.6	9.2	10.7

**TABLE 11. WHEAT PROPORTIONS FOR CONSECUTIVE-DAY DATA
AS DETERMINED USING GROUND TRUTH**

Data	Ground truth	Signature extension proportion minus ground-truth proportion											
		R(S)	REGRES	OSCAR	MOD R	UT	MLEST	ATCOR	MOD OSCAR	R(S/C)	R(C)	UH all	UH fields
F1709-8	24.6	16.7	18.3	19.8	20.2	20.6	18.6	21.5	21.1	27.3	21.1	1.9	2.3
F1673-2	24.6	7.4	2.3	4.9	2.3	6.2	9.3	2.7	2.4	8.7	25.0	17.6	26.8
F1655-4	24.6	0.9	0.9	1.0	1.5	-1.6	7.0	-1.8	0.3	5.9	-0.7	4.7	7.7
F1726-7	24.6	3.2	2.2	2.8	2.8	7.3	3.8	6.8	2.8	6.1	1.6	1.8	-9.5
S1455-4	58.3	-4.1	-7.9	-8.1	-13.2	-6.6	0.2	-7.6	-12.2	-4.9	-17.9	-16.0	-15.2
S1725-4	58.3	-18.4	-18.0	-17.7	-20.1	-23.8	-20.4	-18.7	-19.4	-23.9	-13.4	-3.4	-17.5
E1726-5	44.2	19.5	19.1	21.0	18.6	24.3	22.6	14.5	23.7	27.5	21.3	-7.4	-18.4
Mean absolute values		10.0	9.8	10.8	11.2	12.9	11.7	10.5	11.7	14.9	11.3	8.6	12.6
Std. dev.		7.9	8.4	8.5	8.8	9.6	8.8	7.8	9.9	10.7	9.3	8.7	6.2

**TABLE 12. HAZE CONDITIONS ON
CONSECUTIVE-DAY DATA AS
DETERMINED BY INSPEC-
TION OF IMAGES**

Data	T-SEG	R-SEG
F1709-8	Clear	Clear
F1673-2	Haze	Clear
F1655-4	Clear	Clear
F1726-7	Haze	Clear
S1455-4	Clear	Clear
S1725-4	Clear	Haze
E1726-5	Clear	Haze

**TABLE 13. ANALYSIS OF VARIANCE FOR
OVERALL ACCURACY**

Source	Degrees of freedom	Sum of squares	Mean square	F-factor	Significance
Algorithm (A)	9	217.61	24.18	2.02	6% or 7%
Haze (H)	2	113.69	56.85	4.74	5%
A×H	18	205.32	11.41	.95	NS
Error	40	480.17	12.00		
Total	69	1 016.79			

**TABLE 14. ACCURACY PERCENTAGE FOR
THE THREE DIFFERENT HAZE
CONDITIONS**

Haze condition		Percent accuracy difference
T-SEG	R-SEG	
Haze	Clear	-1.71
Clear	Clear	-4.26
Clear	Haze	-4.82

**TABLE 15. ANALYSIS OF VARIANCE
FOR WHEAT PROPORTIONS**

Source	Degrees of freedom	Sum of squares	Mean square	F-factor	Significance
Algorithm (A)	8	59.77	7.47	X	NS
Haze (H)	2	156.27	78.14	9.42	1%
A×H	16	45.21	2.83	X	NS
Error	36	312.95	8.69		
Total	62	574.20			

TABLE 16. AVERAGE PROPORTION DIFFERENCES
FOR THE THREE HAZE CONDITIONS

Haze condition		Proportion difference
T-SEG	R-SEG	
Haze	Clear	2.0
Clear	Clear	5.8
Clear	Haze	3.9

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TABLE 17. SUMMARY OF TEST RESULTS

Percentage difference between local accuracy and that obtained with various algorithms				Wheat proportions difference from local				Wheat proportion difference from ground truth			
Simulated data		Consecutive-day data		Simulated data		Consecutive-day data		Simulated data		Consecutive-day data	
R(S)	0.0	R(S)	-1.6	R(S)	0.2	R(S)	2.7	R(S)	0.8	UH all	8.6
MLEST	-1.7	MLEST	-1.8	R(C)	1.3	REGRES	3.3	R(C)	1.1	REGRES	9.8
UH fields	-7.1	OSCAR	-2.4	MLEST	2.4	OSCAR	3.6	MLEST	3.0	UH all MLE	10.0
R(C)	-9.4	REGRES	-2.8	UH fields MLE	5.0	MOD R	3.8	UH fields MLE	4.9	R(S)	10.0
UT	-44.1	MOD R	-2.8	UH fields	6.4	UT	4.1	UH fields	6.3	ATCOR	10.5
		R(C)	-3.7	UT	13.5	MLEST	4.2	UT	12.8	OSCAR	10.8
		MOD OSCAR	-3.8			ATCOR	4.3			MOD R	11.2
		ATCOR	-4.3			MOD OSCAR	4.8			R(C)	11.3
		UH fields	-5.1			R(S/C)	5.2			MLEST	11.7
		UT	-6.6			R(C)	6.4			MOD OSCAR	11.7
		R(S/C)	-7.1			UH all	12.8			UH fields	12.6
		UH all	-10.6			UH fields	13.2			UT	12.9
						UH all MLE	13.6			R(S/C)	14.9

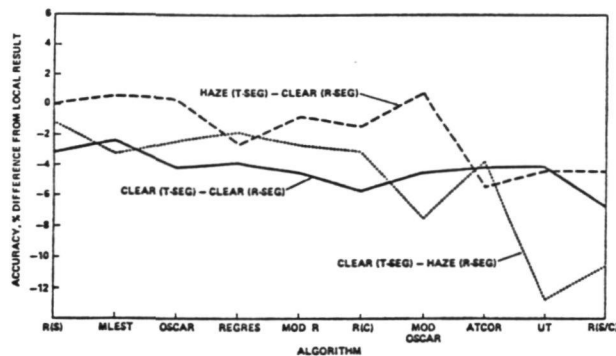


FIGURE 1. HAZE-BY-ALGORITHM INTERACTION.
Overall accuracy difference is shown for
the three haze conditions.

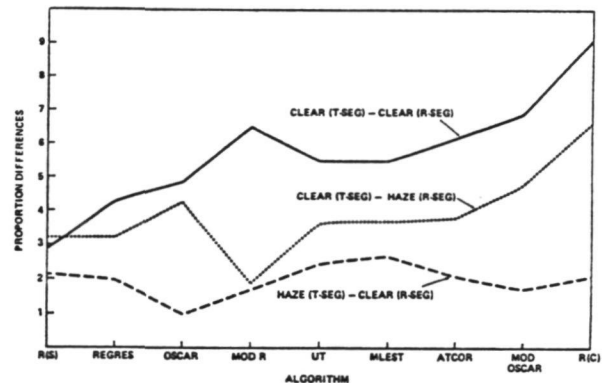


FIGURE 2. HAZE-BY-ALGORITHM INTERACTION.
Proportion differences are shown for the
three haze conditions.

INTERPRETATION OF MULTISPECTRAL AND
INFRARED THERMAL SURVEYS
OF THE SUEZ CANAL ZONE, EGYPT

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SUMMARY

Remote sensing airborne surveys have been conducted, as part of the plan of rehabilitation, of the Suez Canal Zone using I²S multispectral camera and Bendix LN-3 infrared passive scanner. The multispectral camera gives four separate photographs for the same scene in the blue, green, red and near infrared bands. The scanner has been operated in the microwave bands of 8 to 14 microns and the thermal surveying has been carried out both at night and in the day time.

The surveys, coupled with intensive ground investigations, have been utilized in the construction of new geological, structural lineation and drainage maps for the Suez Canal Zone on a scale of approximately 1:20,000, which are superior to the maps made by normal aerial photography. A considerable number of anomalies belonging to various types have been revealed through the interpretation of the executed multispectral and infrared thermal surveys. These anomalous features are related to faults and fractures, salt crusts and salinization, buried channels, surface and subsurface drainage lines, wetness, cultivated lands, sediments submerged under water, suspended sediments, and water bodies. The defined features have been of particular importance in the designing of engineering projects, and in studying the natural resources and environment of the Suez Canal Zone.

A buried channel which is almost completely buried under accumulating wind blown dune sands has been delineated by the multispectral photography and the infrared thermal imagery. The dune sands are also covering the surrounding terrain. The distinction between the dune sands filling the channel and those covering its surroundings is mainly due to the wetness of the sands in the former case while they are dry in the latter.

The distinction of salt crust and other exhibitions of salinization are very important criteria of land management in the Suez Canal Zone, as well as in arid regions at large especially those endangered by saline water intrusion. The Suez Canal Zone is subjected to the invasion of saline water from the Red Sea, Mediterranean Sea and other saline lakes covering large surfaces in the Zone and its environs. Infrared thermal imagery and multispectral photography have proved to be excellent tools in studying the various manifestations of salinization in comparison to normal aerial photography.

INFRARED THERMAL AND MULTISPECTRAL SURVEYS

The Suez Canal Zone in Egypt (Figure 1) has been surveyed in the night time and day time by the Bendix thermal mapper LN-3 and in the day time by the I²S multispectral aerial camera Mark-I. Both are mounted on a twin-engine aircraft AN-2 operating at a speed of 180 km/h. LN-3 is an airborne infrared passive scanner which has been operated during the survey in the microwave bands of 8 to 14 microns, and the thermal anomalies are recorded in a visual fashion on photographic films. On the other hand, the multispectral camera gives for the same scene four photographs simultaneously in four bands of the electromagnetic spectrum, namely the blue (band 1), green (band 2), red (band 3) and near infrared (band 4).

The surveys of the Suez Canal Zone have been conducted in parallel flight lines in an approximate NE-SW direction across the Suez Canal, and the resulting photographs and images are on a scale of about 1:20,000. New maps for the geological and environmental units, structural and other lineaments, and drainage on a scale of 1:25,000 have been prepared for the Suez Canal Zone based on the previously mentioned surveys, as well as on the normal black and white aerial photographs (El Shazly, et al., 1975). Mosaics have been prepared from the photographs of band 4 of the multispectral camera and from the night time infrared thermal images of the thermal mapper to help in the construction of the maps in question, while other images and photographs have been utilized in the mapping separately.

In the present work examples are given illustrating the advantages of using the multispectral photography and infrared thermal imagery in an environment such as that prevailing in the Suez Canal Zone, which is covered by an arid desert with cultivated lands irrigated by fresh Nile water introduced into the Zone through artificially dug canals. Notable features in the Zone are manifested by salinization and salt water intrusion from the Mediterranean Sea, Red Sea and various saline water bodies including Lake Manzala, Lake Timsah and the Bitter Lakes (Figure 1). The examples are classified into those illustrating lithology and environment, structural lineaments, and drainage (wetness) features. The classification of the thermal anomalies is in agreement with that proposed by El Shazly, Abdel Hady and Morsy (1974).

DRAINAGE FEATURES AND BURIED CHANNEL

The drainage systems are very important features in the Suez Canal Zone as in most deserts of the world where they act as channels for rainfall and thus they play a significant role in groundwater accumulation and distribution. The multispectral and infrared thermal surveys have been found to be of particular use in delineating the drainage systems of the Suez Canal Zone especially where the land surface is dominated by featureless plains. The utilization of airborne infrared techniques in elucidating surface and subsurface drainage lines have been demonstrated by Abdel Hady, Abdel Hafez and Karbas (1970); El Shazly, Abdel Hady and Morsy (1974); etc. In multispectral photography not all the bands are equally good for this purpose. It has been demonstrated in this respect that the drainage lines are most clear in the photographs of band 1 (Figure 2), less clear in those of bands 2 and 4, and least defined in those of band 3 (Figure 3).

In El Devreswar west locality, an artificial channel has been discovered by the night time infrared thermal and multispectral aerial techniques. This channel was almost completely buried under dune sands and the same materials cover the surrounding terrain. The sands filling parts of the buried channel are wet, while they are dry in the surrounding sand dunes. In the multispectral aerial photograph of band 2, the wet parts in that buried channel show dark tone in contrast to the lighter tone of the surrounding sand dunes, while the dry parts show light grey tone with a notable trace following the trend of the buried channel (Figure 4). In the infrared thermal image the wet parts of the buried channel show dissected patches in white tone arranged in a nearly straight line, while the dry parts show dark tone indicating colder temperature at about 2 a. m. which is the time of the night time thermal imagery. The direction of the buried channel is shown by an arrow in the image (Figure 5). The estimated width of the buried channel is about 10 to 12 m, its trend is NW-SE and it is located 7 km to the north west of the Serabeum Station. The other white patches appearing in the same figure are wet land sometimes covered by a thin layer of water and vegetation, a broad light tone patch appearing in the image corresponds to cultivated land.

STRUCTURAL FEATURES

Although the night time is sometimes superior for conducting infrared thermal imagery because it produces an end product free of extraneous solar interferences and has proved to be suitable for detecting anomalies related to geological structures, the day time, especially the late afternoon imagery, however,

may display good enhancement of topography and linear elements such as faults which often show in clear manner at that time. An example of day time imagery of linear features is the delineation of two faults of NW-SE trend which attain lengths of 2 and 2.5 km respectively on the infrared thermal image of a locality lying on the eastern side of the Little Bitter Lake (Figure 7). On the other hand, these faults are hardly recognizable on the normal aerial photograph of the same locality (Figure 6). In the day time infrared thermal images, the topographic features are notable and the land-water interface is also clearer as the water appears black or with darker tone while the land shows lighter tone.

LITHOLOGIC AND ENVIRONMENTAL FEATURES

There are many examples to illustrate such features in the Suez Canal Zone. One of these is demonstrated by comparing a night time as well as a day time infrared thermal image with a normal aerial photograph at El Ballah Island where a layer of rock salt and wet salty mud are present in association with other sediments and water bodies to the west of El Ballah Island in the Suez Canal Zone. In the normal aerial photograph (Figure 8), the rock salt layer which is some 10 to 20 cm thick is hardly seen and it is also difficult to distinguish between wet salty mud and the surrounding sediments and water bodies. In the day time infrared thermal image of the same locality (Figure 9), the rock salt layer and wet salty mud are clearly visible from the other surrounding sediments or water bodies. The salty layer and wet salty mud show with lighter tone in contrast to the darker tone of the water and other wet sediments because of their thermal anomalies. On the other hand, the night time infrared thermal image of the same locality (Figure 10) clearly shows the difference between the rock salt layer and the wet salty mud. In the latter image, the rock salt layer appears white due to its higher temperature, while the wet salty mud shows with light grey tone in contrast to the bright white tone of the water bodies.

The applicability of day time and night time infrared thermal imagery in studying the small water bodies in the Suez Canal Zone is demonstrated also by examining the previously mentioned images of El Ballah Island. The configuration of the boundary of the water body including its very shallow marginal parts is well defined in the night time image (Figure 10), while only the relatively deep part is shown in the day time image (Figure 9).

The multispectral photographs, especially of bands 2 and 1, proved to be of particular use in revealing submerged sediments under the water surface to various depths and suspended sediments in the water, while certain depth of the water bodies and shorelines are clearly recognized. These features are important for studying recent sedimentation in the lakes in the Suez Canal Zone, and they are illustrated by comparing a multispectral aerial photograph of band 2 of the western shore of the Little Bitter Lake (Figure 12) with a normal black and white photograph of the same locality (Figure 11).

Another interesting example of the application of multispectral photography in revealing lithologic and environmental units is the recognition of white limestone outcrops in low relief hills belonging to the Middle Miocene El Shatt Formation in the multispectral photograph of band 2 eastwards of Lake Timsah (Figure 14), while they can be hardly recognized in the normal aerial photograph (Figure 13). Further important uses of multispectral photography especially in band 4 incorporate the distinction between already cultivated lands which appear in white to light grey tones and those being prepared for cultivation which appear divided in divisions of dark gray or grey tones depending on the availability of water in each division.

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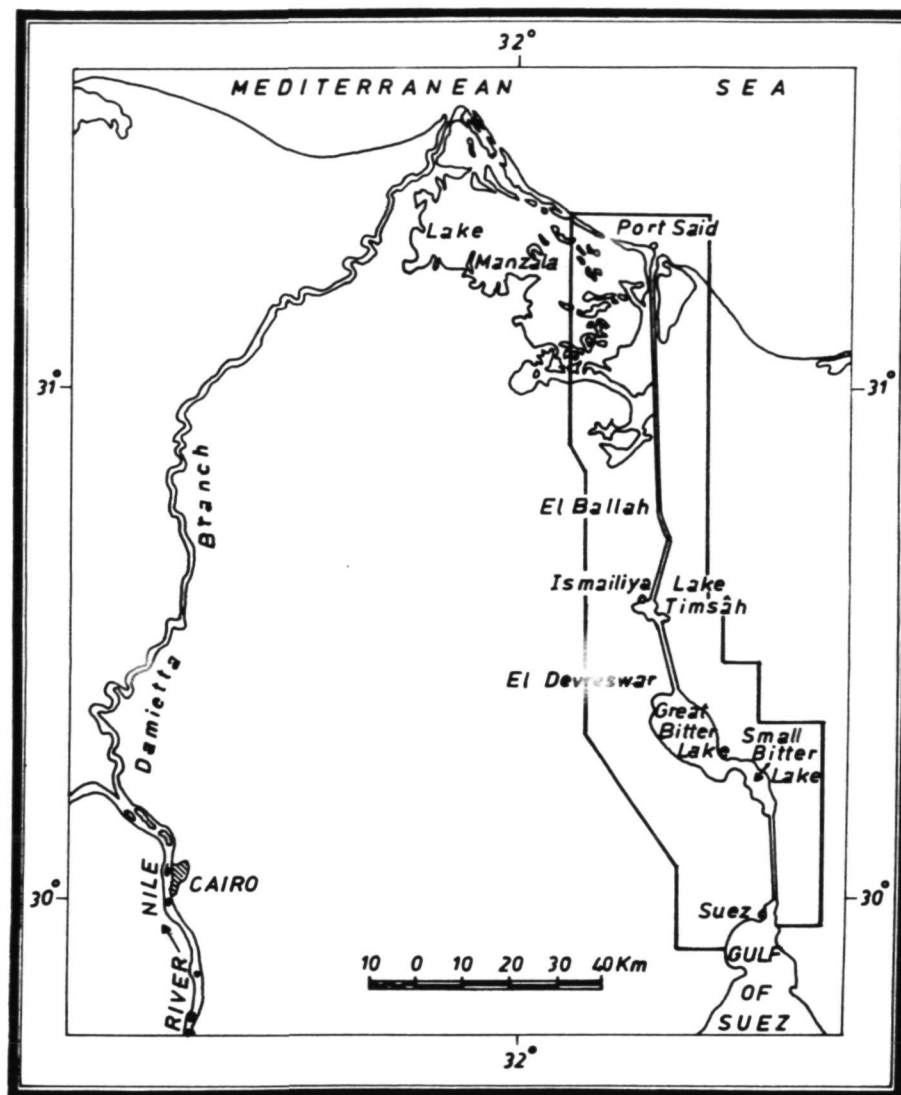


FIGURE 1. LOCATION MAP OF THE SUEZ CANAL ZONE, EGYPT.

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FIGURE 2. MULTISPECTRAL AERIAL PHOTOGRAPH, BAND 3 (1974) WHERE THE DRAINAGE LINES ARE NOT WELL DEFINED. WESTWARD OF SUEZ. APPROXIMATE SCALE 1:20,000.

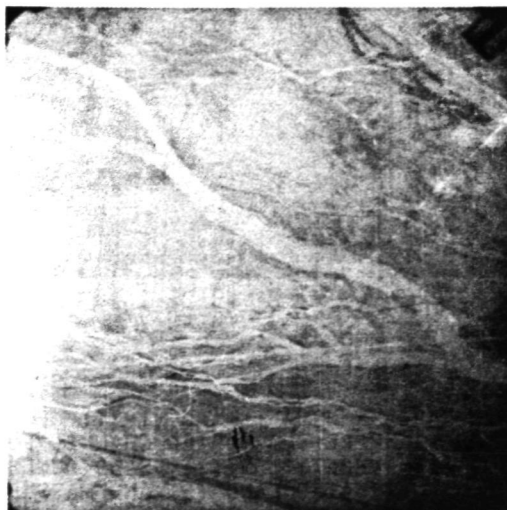


FIGURE 3. MULTISPECTRAL AERIAL PHOTOGRAPH, BAND 1 (1974) OF THE SAME LOCALITY SHOWN IN FIGURE 2 WITH THE DRAINAGE LINES SHARPLY DEFINED.

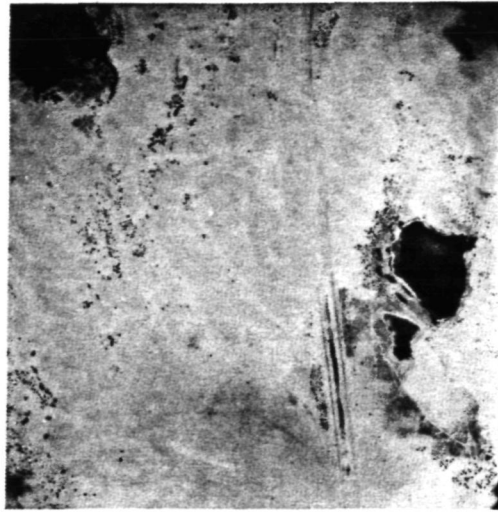


FIGURE 4. MULTISPECTRAL AERIAL PHOTOGRAPH, BAND 2 (1974) WHERE THE BURIED CHANNEL IS CLEARLY DEFINED. EL DEVRESWAR WEST LOCALITY. APPROXIMATE SCALE 1:20,000.

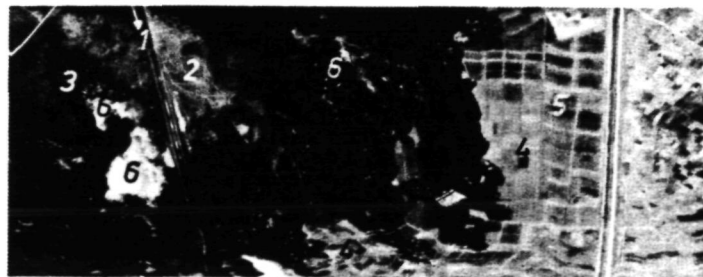


FIGURE 5. NIGHT TIME INFRARED THERMAL IMAGE (1974) FOR THE SAME LOCALITY SHOWN IN FIGURE 4 WHERE THE BURIED CHANNEL POINTED TO BY AN ARROW (1), WET LAND WITH VEGETATION (2), SAND DUNES (3), CULTIVATED LAND (4), DIVIDED UNCULTIVATED LAND (5) AND MARSHES ARE EASY TO DIFFERENTIATE.

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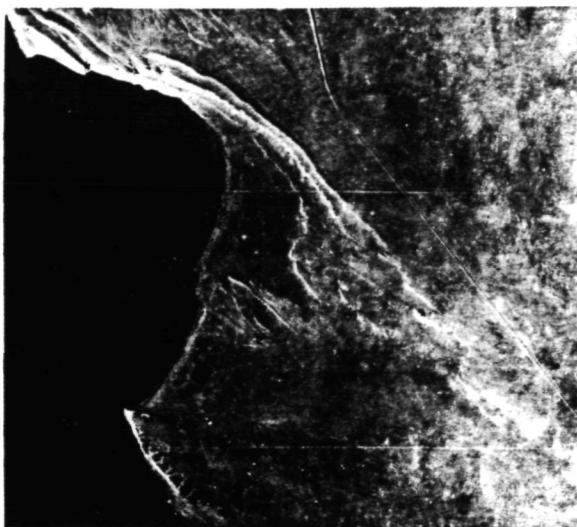


FIGURE 6. NORMAL AERIAL PHOTOGRAPH (1956) WHERE FAULTS ARE NOT CLEARLY OBSERVED. EASTERN SIDE OF LITTLE BITTER LAKE. APPROXIMATE SCALE 1:20,000.

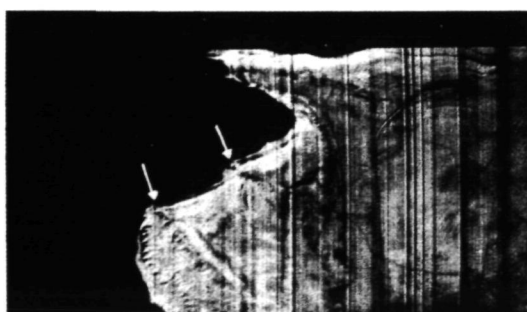


FIGURE 7. DAY TIME INFRARED THERMAL IMAGE (1974) OF THE SAME LOCALITY SHOWN IN FIGURE 6 WHERE FAULTS POINTED TO BY ARROWS ARE EASY TO DISTINGUISH.

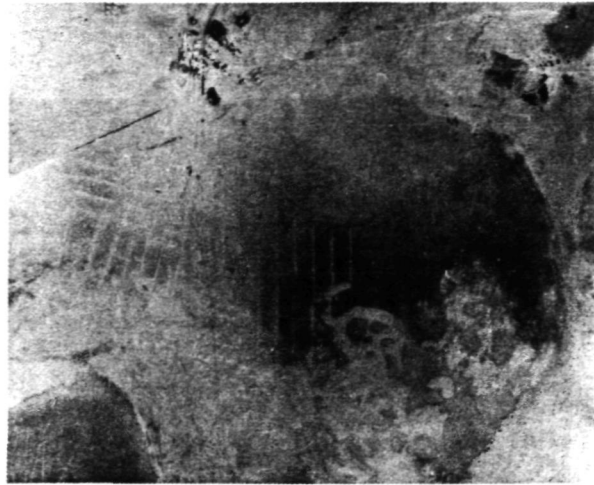


FIGURE 8. NORMAL AERIAL PHOTOGRAPH (1956) WHERE THE ROCK SALT LAYER IS NOT CLEARLY DELINEATED. WEST EL BALLAH ISLAND. APPROXIMATE SCALE 1:20,000.

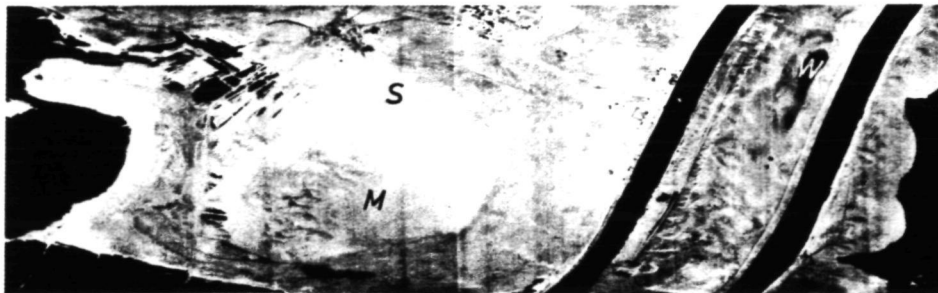


FIGURE 9. DAY TIME INFRARED THERMAL IMAGE (1974) WHERE THE ROCK SALT LAYER (S) AND THE WET SALTY MUD (M) ARE NOTED BUT NOT POSSESSING SHARP CONTACTS. THE RELATIVELY DEEP PART OF THE WATER BODY (W) IS ONLY SHOWING. WEST EL BALLAH ISLAND.

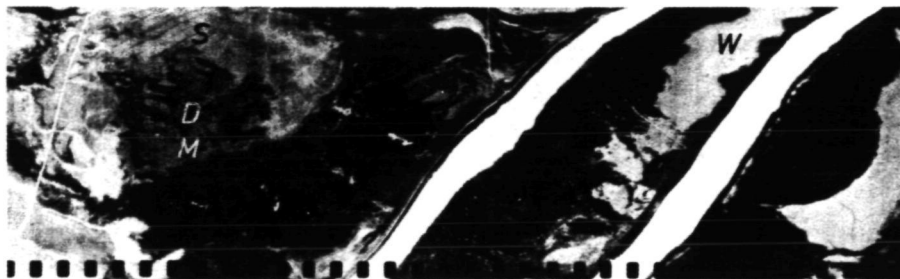


FIGURE 10. NIGHT TIME INFRARED THERMAL IMAGE (1974) WHERE THE ROCK SALT LAYER (S), THE WET SALTY MUD (M) AND THE WATER BODY (W) ARE IDENTIFIABLE WITH SHARP BOUNDARIES. SAND DUNES (D) AND WET DRAINAGE LINES POINTED TO BY ARROWS ARE CLEARLY DIFFERENTIATED. WEST EL BALLAH ISLAND.

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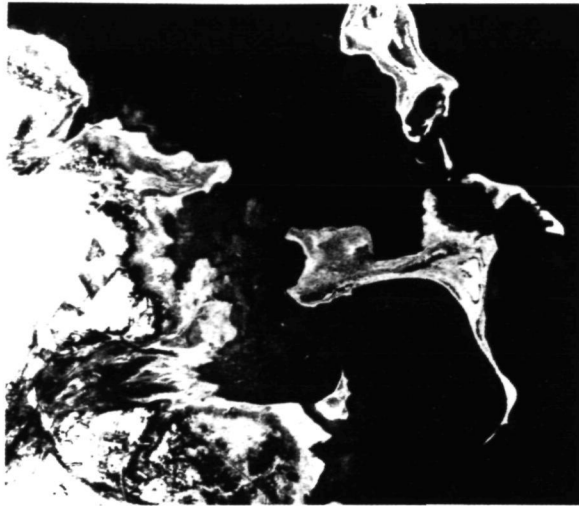


FIGURE 11. NORMAL AERIAL PHOTOGRAPH (1956) FOR THE WESTERN SHORE OF LITTLE BITTER LAKE. APPROXIMATE SCALE 1:20,000.



FIGURE 12. MULTISPECTRAL AERIAL PHOTOGRAPH, BAND 2 (1974) SHOWING NOTABLE SUSPENDED SEDIMENTS NEAR THE WESTERN SHORE OF LITTLE BITTER LAKE. THE CONFIGURATION OF THE ISLAND IN THE LAKE IS DIFFERENT IN 1974 AS COMPARED TO 1956 DUE TO THE EROSION AND SEDIMENTATION PHENOMENA. APPROXIMATE SCALE 1:20,000.



FIGURE 13. WHITE LIMESTONE OUTCROPS OF LOW RELIEF APPEARING HAZY IN NORMAL AERIAL PHOTOGRAPH. EASTWARD OF LAKE TIMSAH. APPROXIMATE SCALE 1:20,000.

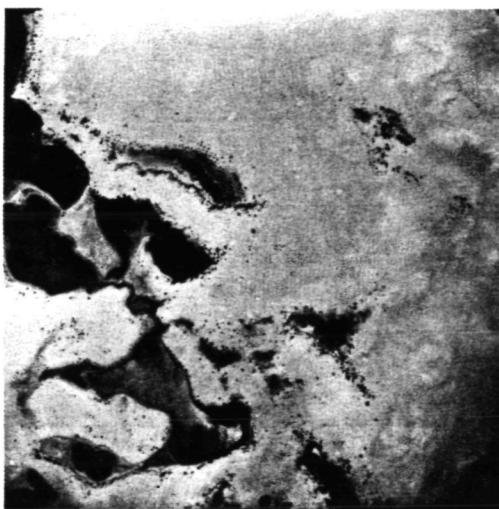


FIGURE 14. THE SAME WHITE LIMESTONE OUTCROPS IN FIGURE 13 ARE CLEARLY OBSERVED IN MULTISPECTRAL AERIAL PHOTOGRAPH, BAND 2. APPROXIMATE SCALE 1:20,000.

omit

PRELIMINARY LINEAMENT MAP OF THE

CONTERMINOUS UNITED STATES

W. D. Carter¹, B. K. Lucchitta², and G. G. Schaber²

U. S. Geological Survey

SUMMARY

A Landsat-1 (formerly ERTS-1) mosaic of the conterminous United States, compiled for NASA by the U. S. Department of Agriculture (Soil Conservation Service), has provided an unequalled opportunity to study the two-dimensional, surficial geometry of our land. The mosaic has been reproduced at two basic scales: 1:5,000,000 and 1:1,000,000, and in two spectral bands: band 5=0.6-0.7 μ m, and band 7=0.8-1.1 μ m, respectively.

The smaller-scale mosaic (band 5) was analyzed for the presence of large-scale, natural lineaments in order to rapidly outline possible surface structures. The results of this initial analysis provided the justification for a more detailed study of lineaments on the 16 individual sheets that comprise the 1:1,000,000-scale (band 7) mosaic. The 16 sheets were studied independently by each of the three authors, and the results of their work were later combined onto a common base map. Linear features marked by only one of the authors were noted with dotted lines, by two of the authors with dashed lines, and by all three of the authors with solid lines.

As might be expected, the largest number of lines were dotted, from which we inferred that each person interpreted differently the presence of linear and curvilinear features. This, we believe, is due to differences in personal background, scientific orientation, and perhaps even to interpretation techniques and philosophy. While these subjective differences may affect the relative weighting assigned to each line, the overall result provides a crude yet automatic evaluation of the map as a whole.

Subsequent to compilation, the 16 sheets were reduced to a scale of 1:2,500,000 to conform to the scale of the Tectonic Map and Geologic Map of the United States. Superposition of the lineament map on the Tectonic Map showed where major fault zones were observed, and how they are expressed on the Landsat mosaic. More importantly, however, the overlay indicates areas where lineaments occur that are not expressed as faults or other structures on existing small-scale maps. These areas are potential sites for more detailed studies and field work.

A list of features is provided on the map to show that while most lineaments recognized by all three compilers can be related to fault and fracture systems, not all of these lineaments are of structural or even geologic origin. In addition, arcuate and circular features of both geologic and non-geologic origin were mapped, and will be differentiated as to origin as the evaluation of map features progresses.

1 Reston, Virginia

2 Flagstaff, Arizona

The question arises: of what use are lineament maps? At this time, we are not entirely sure. Lineament maps should be considered as intermediate maps; that is, an interpretation of raw data, much like the conventional interpretations of aeromagnetic maps, gravity maps, or other maps compiled from geophysical data. In this sense, the main value of a lineament map is to serve as a guide for more detailed work which uses published field data, or in preparation for field work. When compared with existing maps showing the distribution of ore deposits or oil fields, the lineament map may aid in the selection of areas for future exploration. When used in conjunction with seismic data describing the occurrence of earthquakes, the lineament map may serve as a guide for locating potential geologic hazards at sites selected for the construction of dams, bridges, or atomic-power plants. The map may also be useful as a basis of comparison for other workers compiling lineament maps. Thus, while the lineament map cannot be used independently of other maps, we believe it has intrinsic value as a tool to provide a better understanding of the geological structure of our planet and the continent on which we live. The authors hope that the lineament map will be used in the contexts cited above, and perhaps contribute to present and future studies of plate tectonics and crustal evolution.

THREE APPROACHES TO THE CLASSIFICATION AND MAPPING OF INLAND WETLANDS

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Donald Malone ²
Paul D. Brooks ³
Virginia Carter ³

ABSTRACT

Three projects representing three approaches to the classification and mapping of inland wetlands are discussed. In the Dismal Swamp project, seasonal, color-infrared aerial photographs and Landsat digital data were interpreted for a detailed analysis of the vegetative communities in a large, highly altered wetland. In western Tennessee, seasonal high-altitude color-infrared aerial photographs provided the hydrologic and vegetative information needed to map inland wetlands using a classification system developed for the Tennessee Valley Region. In Florida, color-infrared aerial photographs were analyzed to produce wetland maps using three existing classification systems to evaluate the information content and mappability of each system. The methods used in each of the three projects can be extended or modified for use in the mapping of inland wetlands in other parts of the United States.

INTRODUCTION

As awareness of the economic and environmental value of wetlands has increased, the classification and mapping of inland wetlands has become a matter of great concern to local, State and Federal agencies. Inland (nontidal) wetlands make up approximately 87 percent of the total wetland acreage of the conterminous United States. Their size ranges from potholes less than one-half hectare in the northern prairies to thousands of hectares in the Great Dismal Swamp, the Okefenokee Swamp, and the Lake Agassiz Peatlands Natural Area. The three projects discussed in this report concern the development of remote sensing techniques to classify and map inland wetlands in Virginia-North Carolina, Tennessee, and Florida, using three different approaches.

Wetlands are dynamic ecosystems definable in terms of hydrology, vegetation, and soils, but difficult to map because of water level (boundary) fluctuations. A photograph, or a field visit, results in a record of the location of the water's edge at one isolated instant in time. Vegetative composition, soils, or abrupt topographic changes may serve to indicate the boundary of a wetland or wetland class. Often, however, the change in vegetation, soil, or topography is gradual and it is difficult, therefore, to place a meaningful boundary within the continuum from permanently wet to permanently dry.

Recent research and published scientific reports have shown that color-infrared (IR) aerial photographs can be used for detailed mapping of inland wetland vegetation cover types (Seher and Tueller, 1973; Neilsen and Wightman, 1971; DeSteiguer, 1975; Carter and Stewart, 1975; Carter and others, 1976). The use of high-altitude color IR photographs to document surface-water boundaries in wetlands has been discussed by Carter and Stewart, 1975, and by Moore and North, 1974.

U.S. Geological Survey (USGS) topographic quadrangles are often used as a base map on which to transfer information interpreted from aerial photographs. The most commonly used scale is 1:24,000, but maps of the 1:250,000-scale and the new 1:100,000-scale series are also used for this purpose. Orthophotoquads, interim map products made by rectification of black-and-white (B/W) aerial photographs, also provide an extremely useful and up-to-date base map. The natural photographic detail is preserved and there is minimal cartographic treatment (place names and a grid reference system) to obscure the mapped detail. In all the projects discussed below, USGS base maps were used to present wetland information.

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THE GREAT DISMAL SWAMP

Background and objectives

The USGS and the U.S. Fish and Wildlife Service (FWS) have a continuing cooperative project in the Great Dismal Swamp, Virginia-North Carolina. The FWS has the responsibility for evaluating and developing management priorities for the 56,630 ha primary area of the swamp. Management decisions must be based in part upon an understanding of the vegetative communities and their relationship to the hydrologic regime of the Great Dismal Swamp. The objectives of the project include using remotely-sensed data to map the vegetative cover and to study the hydrology of the swamp.

Test site

The Great Dismal Swamp is an 84,000 ha forested wetland located on the Virginia-North Carolina border on the mid-Atlantic coastal plain. It is developed on organic soils ranging in depth from 4 m in ancient drainage channels to less than 0.3 m along the outer edges and on poorly drained mineral soils. Lake Drummond, approximately 4 km in diameter, is almost centrally located within the gently sloping west-east gradient of water flow.

Man-induced alterations such as fire, timbering and ditching, as well as geographic location, have created a remarkable diversity of vegetative communities in the Great Dismal Swamp. The vegetative composition includes a variety of deciduous and evergreen, broad-leaved and needle-leaved tree species, and deciduous and evergreen shrubs, vines and herbaceous plants. Because of this diversity and the inaccessibility of interior parts of the swamp, the traditional methods of ground sampling have proven to be too costly and time-consuming to successfully identify and describe the present vegetation.

Materials and methods

National Aeronautics and Space Administration (NASA) seasonal high- and low-altitude color IR photographs were used to identify and map specific swamp vegetative communities at scales of 1:100,000 and 1:24,000. On winter, leaves-off photographs, peripheral land-use or land cover can be identified, dendritic drainage patterns can be seen extending from the upland into the swamp, and evergreen species, both broad-leaved and needle-leaved can be identified. Using these winter photographs supplemented with growing season photographs, evergreen and deciduous canopy and understory can be separated and several deciduous classes identified.

Early black-and-white (B/W) aerial photographs, in combination with timber records and state fire reports, were used to prepare maps showing approximate dates and extent of timbering and fires. These historical maps for 1937-38, 1952 and 1971 were designed to overlay the vegetation maps.

USGS prepared a 1:100,000-scale mosaic of the 16 USGS 7.5-minute orthophotoquads containing the Great Dismal Swamp. Classes were interpreted from the color IR photographs and historical B/W photographs, and delineated on stable base mylar registered either to the mosaic or to the individual orthophotoquads.

Geometrically corrected and temporally registered Landsat digital data from April and February 1974 have also been used to classify and map the vegetative cover in the Great Dismal Swamp. Vegetative cover classes were grouped into dominance types and subclasses according to the new FWS wetland classification system (Cowardin and others, 1976). Four Landsat data sets were analyzed on the Interactive Digital Image Manipulation System (IDIMS) at the Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, S. D.: (1) April data all multispectral scanner (MSS) bands (2) February data all MSS bands (3) MSS bands 5 and 7 from April and February and (4) all 8 MSS bands from April and February. Classifications have also been made with Landsat digital data from the same data sets and from different dates using the General Electric 1/ Image-100 (Carter and others, 1977), and the Purdue University Laboratory for Applications of Remote Sensing System (LARSYS). We are using sample plots and IDIMS algorithms to measure the accuracy of these classes and previous classifications.

1/ The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

Winter Landsat images clearly show the extent of surface water in areas with deciduous cover. This information helps to understand the damming and diversionary effects of roads and ditches. It is also important as an aid in site selection for vegetation and hydrology studies.

Map products

The 1:100,000- and 1:24,000-scale vegetative cover maps show classes based on dominant canopy species and type and extent of understory (Fig. 1). Ten canopy classes, the deciduous classes ranked in order of water tolerance, and three associated understory classes were designated. Due to the complex mixtures of species throughout the swamp, classes were frequently combined in order of dominance. These class combinations have resulted in over 40 separate canopy designations and 240 specific community delineations. The maps provide up-to-date information which can be used directly in making management decisions and for selecting sites for intensive study. The historical maps show patterns of regeneration following disruptive events. By combining the information from the historical and present-day vegetative cover maps with biological and climatic data, it is possible to interpret the responses of vegetation to various environmental influences and to establish successional trends, thus providing additional data on which to make management decisions.

For the Landsat classification with IDIMS, 18 dominance types were established for the swamp on the basis of season, dominant canopy species and, in some deciduous classes, on type of understory. The subclasses and dominance types vary in number and composition according to season of data acquisition. Percentage estimates for the swamp subclasses were as follows: shallow water/benthos, 2.2 percent, broad-leaved evergreen forested wetland, 6.5 percent, needle-leaved evergreen forested wetland, 16.0 percent, broad-leaved deciduous forested wetland, 67.7 percent, narrow-leaved deciduous forested wetland, 1.0 percent, broad-leaved evergreen shrub wetland, 5.0 percent, and altered, 1.6 percent.

WESTERN TENNESSEE

Background and objectives

The USGS and the Tennessee Valley Authority (TVA) are presently conducting a cooperative wetland mapping project in western Tennessee. This experimental project was initiated in response to local, State and Federal management needs and concern over the loss of wetland habitat in the area. The wetland maps were designed to provide baseline information for resource management, including the information needed for:

- (1) legislative or regulatory requirements,
- (2) location of seasonally inundated and permanently flooded areas,
- (3) decisions on sites for agricultural, residential, or industrial development,
- (4) wildlife management and habitat acquisition,
- (5) development of recreational opportunities,
- (6) monitoring change.

The three major objectives of the project were; one, to develop and test a wetland classification system for the Tennessee Valley Region, two, to test the utility of seasonal high-altitude color IR photography for mapping the proposed wetland classes and subclasses as well as surrounding land-use, and three, to use seasonal data to study wetland boundary dynamics (hydrologic fluctuations) and to relate boundaries to stage (water level). The primary emphasis in this paper is to describe the preparation of wetland maps for four sites in western Tennessee using the wetland classification system developed during the study.

Development of the classification system

The classification system developed is based primarily on vegetation and on the frequency and duration of inundation (Virginia Carter and J. H. Burbank, unpub. data 1977). Several modifications were made in the initial system as the mappability of the classes was tested. The final system is thus designed to derive the optimum blend of interpretable and mappable wetland information from the data source, in this case high-altitude, color IR photography.

Test sites

Four test sites, Reelfoot Lake, Hatchie River Bottoms, White Oak Swamp, and Duck River dewatering area, were selected for classification and mapping. These sites, all located in western Tennessee, were considered to be representative of the diversity of wetlands encountered in the Tennessee Valley Region. Reelfoot Lake is a tectonic feature created on the Mississippi

River flood plain by the New Madrid Earthquakes of 1811 and 1812. This relatively shallow and heavily vegetated lake, surrounded primarily by agriculture and upland forest, has the most diversity in wetland types of any site mapped. Hatchie River Bottoms is an extensive and classic example of Bottomland Hardwood extending along both sides of the Hatchie River. During much of the year, including the growing season, the water is contained within the river channel, but in the late winter and spring and for short periods following very heavy rain in the drainage basin, a wide area of forested flood plain and some surrounding agricultural land is flooded.

The two remaining sites are located in Tennessee River basin and are more or less affected by controlled water levels in the Tennessee River. The Duck River dewatering area, located where the Duck River enters the Tennessee River, is surrounded by a levee, and the water level is controlled by TVA. The area contains many acres of agricultural land that are flooded annually and, until recently, a program for control of vegetation was carried on by TVA. The White Oak Swamp is located along White Oak Creek which has been channelized and the dredge spoil piled on the channel banks. Very few connections were retained between the main channel and the low areas behind the spoil banks and beavers have now dammed most of these. The impounded water has created many acres of Dead Woody Swamp, partially regenerated to Shrub Swamp and surrounded by Forested Swamp or Bottomland Hardwood.

Materials and general methods

The primary data source for mapping the land-use and wetland classes and subclasses was high-altitude color IR photography obtained by NASA. The scale of the aerial photographs is approximately 1:130,000. Natural water-level fluctuations, seasonal growth of emergent aquatic vegetation and continuous tree cover in many areas necessitated the use of seasonal photography. Photographic coverage was therefore obtained in February (high water, leaves-off), October (late growing season), and November (low water, leaves-off) of 1975.

A mapping scale of 1:24,000 was selected for several reasons. The small size of some wetland classes necessitated a large mapping scale. The 1:24,000-scale USGS topographic map series covers all of the sample test sites and provides additional data for evaluating wetlands; e.g., topography, cultural features, and surrounding drainage patterns. A published map, which meets the National Map Accuracy Standard (NMAS), also provides reliable planimetric control for locating wetland classes.

The delineation of the 6 wetland classes, 12 wetland subclasses and the surrounding land-use was done manually by an experienced photointerpreter. The photointerpreter also took part in the preliminary field checking and assisted in modifying the subclasses to maximize the information derived from the aerial photographs. Table 1 shows the classification system and the photographic criteria for mapping the wetlands. The interpreted data were transferred to stable base drafting film overlayed on the appropriate 1:24,000-scale map. The registration of wetland data was accomplished by the use of a Bausch and Lomb Zoom Transfer Scope. For less detailed mapping of the surrounding land-use, a Kelsh stereoplotter was used.

Records from gages on Reelfoot Lake (USGS and FWS) and Hatchie River (USGS and U.S. Army Corps of Engineers) were used to determine the water stage on the dates of the overflights. A stage-duration curve was developed from five years of stage record on Reelfoot Lake.

In addition to the preliminary field checking, the final map products were extensively checked in the field at the Reelfoot Lake site, with somewhat less intensive checking for the other three sites. At Reelfoot Lake, the field checking included running transects to determine both accuracy of wetland classification and boundary placement.

Map products

Wetlands and adjacent land-use were mapped in the four sites on a total of 15, USGS 7.5-minute quadrangles: Reelfoot Lake (5), Hatchie River Bottoms (5), Duck River dewatering area (2), and White Oak Swamp (3). The final map product is a clear positive overlay keyed to the appropriate 1:24,000 sheet. The overlay is on stable base material and can be reproduced in several forms, including a clear positive, matte finish positive, or a blue-line paper print. Wetlands for the Tiptonville quadrangle (part of the Reelfoot Lake site) were color separated and printed using the 7.5-minute topographic map for base information to produce a 5-color lithographic product. The stage-duration curve for Reelfoot Lake was placed on the map collar. Copies of this map are available through TVA Mapping Services Branch, Map Information Records Unit, 100 Haney Building, Chattanooga, Tenn. 37401.

AUBURNDALE, FLORIDA

Background and objectives

USGS 1:24,000-scale topographic maps have shown wetlands as a hydrologic feature for many years, and are the primary cartographic base for the Nation's wetlands. They are produced according to NMAS, and the relative internal accuracy of the map is likely to be better than NMAS. The various wetlands are shown on USGS maps as follows:

1. Marsh --- marsh or swamp symbol without a color overprint
2. Submerged marsh --- marsh or swamp symbol overprinted with solid blue tint
3. Swamp --- marsh or swamp symbol overprinted with green tint
4. Submerged swamp --- marsh or swamp symbol overprinted with both solid blue and green tint
5. Mangrove swamp --- mangrove symbol overprinted with green tint

While reasonably accurate and acceptable in the main the marsh or swamp symbol bears little or no relation to the vegetation species; the criteria are unreliable at the marsh or swamp boundary; and at publication the definitive outline is lost by nature of the marsh or swamp symbol. Since the maps do not show a well-defined wetland boundary (except where it coincides with a shoreline), the map accuracy standards cannot be applied in the area between wetlands and upland.

USGS has been experimenting with new compilation methods and map products using three different wetland classification systems. The objectives of this research project were: (1) to test the feasibility of mapping and classifying inland wetlands on USGS 7.5-minute quads in more detail than is presently shown; (2) to develop or identify a standard definition and classification system for use by USGS; and (3) to prepare sample products for user evaluation. The following discussion focusses on the Auburndale, Fla., 7.5-minute quadrangle, for which sample map products have been prepared for evaluation by selected users.

Wetland classification systems

The three classification systems (Figure 2) tested on the Auburndale, Fla., quadrangle are the Martin (Martin and others, 1953), Anderson (Anderson and others, 1976), and Cowardin (Cowardin and others, 1976). Two of these classification systems were available at the beginning of this project; the third, Cowardin, was obtained in draft form in March 1976. These three classification systems were developed for nationwide usage. However, they differ in scope, terminology, and criteria, and provide varied approaches to the mapping of wetlands on USGS 7.5-minute quads. Many excellent classification systems have been written for local or regional conditions, but they cannot usually be applied to different regions of the country. Thus, they are not applicable to a national wetland mapping program nor to standard treatment on USGS topographic quadrangles. These local classifications were not considered in this research.

The Martin system was developed for the first FWS Wetland Inventory in 1954 (Shaw and Fredine, 1956). Its single primary purpose was the assessment of the amount and types of valuable waterfowl habitat. The wetland classes are based on vegetation and presence of water or wet soil. Only the eight wetland types in the Inland Fresh Areas category were considered in the current research project.

The Anderson system is a complete land-use and land cover classification system based almost entirely on the use of remote sensor data. The system, hierarchical in nature, proceeds from the very general at Level I to the more specific at the lower levels. Wetland, one of the nine Level I categories, is divided into Forest and Non-Forested at Level II. For this project, the Level II wetland classes were subdivided into Levels III and IV for mapping at 1:24,000 scale.

The Cowardin system, which will replace the earlier Martin system, by FWS for a new national inventory of wetlands. It is a hierarchical, descriptive system based upon vegetation, soils, and hydrology and is intended to facilitate inventory and comparison of wetland types on a national basis. The system is intentionally left open-ended to allow wetland data to be added which has been gathered through the acquisition of additional source material and (or) field inventory. Ultimately, this would complete the definition of wetland parameters that could be identified using remote sensing techniques.

Test site

The Auburndale, Fla., 7.5-minute quadrangle, located approximately midway between Tampa and Orlando, was selected as a test site for two reasons: one, geology within the area covered by the map is complex; and two, a variety of wetland types are present. The eastern third of the quadrangle is covered by the Central Florida Highlands which is underlain by limestone with many sink-hole lakes interconnected by canals with control dams. The central and western portions of the quadrangle are relatively flat lowland covered by marine shore deposits, and extensive areas of strip mining located in the western edge. The higher, well-drained ground of the limestone terrain is occupied by large citrus groves. The rest of the highland area is urban, and urban development is spreading into the lower elevations west of the limestone ridge, sparing the citrus plantations.

Materials and methods

Existing superwide B/W aerial photographs at 1:20,000 scale acquired on November 30, 1971, and quad-centered 1:76,000-scale color IR aerial photographs taken on December 1, 1972, were used to interpret and delineate the wetland boundaries and classes. The photo-image bases at 1:24,000-scale were made from the color IR photographs by overprinting on yellow scribecoat from a rectified B/W film transparency. The three wetland classification systems were then stereo-compiled from the aerial photographs on the photo-image bases.

Map products

Three inland wetland classification maps were prepared at 1:24,000 scale on an orthophoto base of the Auburndale, Fla., 7.5-minute quadrangle using the Martin, Anderson and Cowardin wetland classification systems respectively. Each map contains a geographic reference system, major geographic names (cities and lakes), and appropriate standard map collar information. In addition, an explanation (legend) depicting the map symbols for the categories of the appropriate wetland classification system is contained in the collar on each map.

Wetland classification and mapping proved very difficult using the Martin system definition. The Martin system does not appear to be suited for large scale wetland mapping on an operational basis. The Anderson system in the expanded form (Levels III and IV) is limited in its utility by geographic considerations and by the difficulty of applying uniform map symbolization. The Anderson system is designed as a complete land-use and land-cover system, so wetland can potentially be classified as agricultural land, water or one of the other Level I categories.

The Cowardin definitions, of the three classification systems tested, were the easiest to apply in the photointerpretation and delineation of the wetland categories. Using remote sensing techniques and the Cowardin system, the USGS was able to compile a greater density of wetland classes than could be compiled with either the Martin or Anderson systems. We concluded, however, that neither a classification system nor a map need contain all of the information gathered during a complete wetland inventory. With the modified Cowardin system, we have produced a generalized wetland map using remote sensing techniques, and of the three systems tested, it is the preferred system.

SUMMARY AND CONCLUSIONS

The three studies presented in this paper differ significantly in their approach to a common problem, the classification and mapping of inland wetlands. In the Great Dismal Swamp, 56,630 hectares of forested wetland have been subdivided on the basis of dominant canopy and under-story species. Information from seasonal color IR aerial photographs was transferred to orthophoto base maps at 1:100,000- and 1:24,000-scales. Geometrically-corrected and temporally-registered Landsat digital data was also used to classify vegetative cover. It has been concluded from the Great Dismal Swamp project that:

- 1) Color IR photography from both the winter (leaves-off) and growing season (leaves-on) is essential for detailed vegetative cover (habitat) mapping.
- 2) Transfer of information to a planimetrically correct orthophotomap base results in a product which may be reproduced at any convenient size, can aid in directing intensive field studies, and can be used to illustrate vegetative relationships, succession, and trends.

- 3) The winter data give information on surface-water drainage patterns and concentration within the swamp, thus giving some needed perspective on the damming effects of roads and the diversionary effects of ditches. These data are particularly useful in selecting sites for ground-water observations.
- 4) B/W historical aerial photographs can be interpreted to produce maps that illustrate successional trends in altered areas.
- 5) Landsat temporal digital data can be used to classify vegetative cover and thus are a strong potential tool for future monitoring of vegetative trends.

In Tennessee, seasonal high-altitude color infrared photographs were used to map wetland classes using a classification system specifically designed for the Tennessee Valley Region as part of the project. Fifteen maps were compiled on U.S. Geological Survey 7.5-minute quadrangle base maps, and one map was made into a color lithograph product. Stage information was placed on the map collars of 9 of the 15 maps. The conclusions reached from this project are the following:

- 1) A new classification system was developed for inland wetlands in the Tennessee Valley Region.
- 2) Seasonal color IR photographs provide sufficiently detailed information to map wetland areas as small as 0.43 ha in area and 20 m in the smallest linear dimension. A minimum of field observations is required, although field checking of final or interim products is always advisable.

The critical periods for aerial photography were determined to be the leaves-off, high-water season, the growing season, and the leaves-off, low-water season. This combination provided a maximum of information for identification and delineation of wetland classes.

- 3) Dates of aerial photographs can be related to stage records to give an idea of range in water-level fluctuation and placement of wetland boundaries within this range.

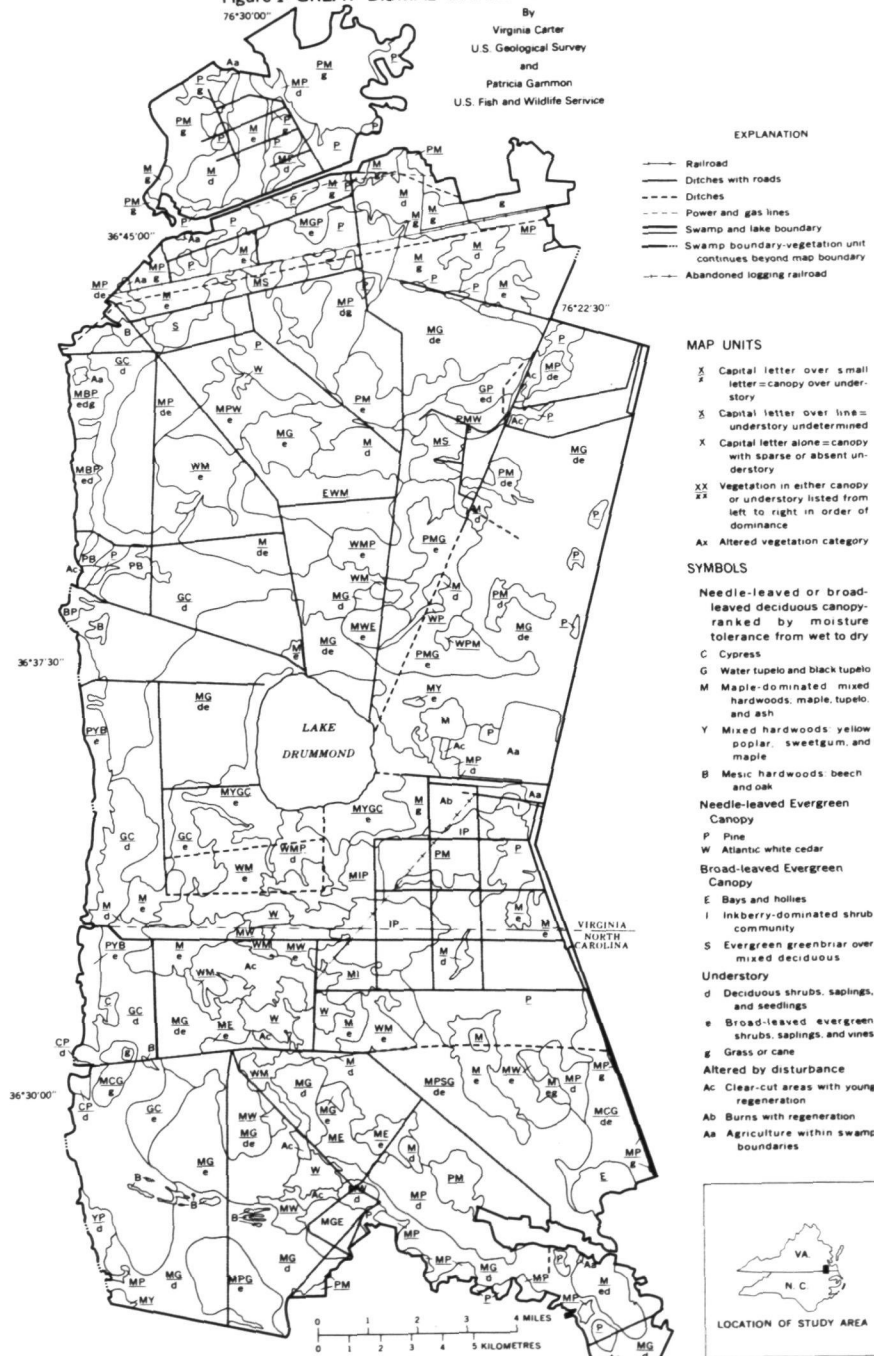
In Florida, wetlands on the Auburndale 7.5-minute quadrangle were mapped to test three different wetland classification systems. It was concluded from this study that:

- 1) Inland wetland boundaries interpreted from quad-centered, color IR aerial photographs supplemented with low-altitude B/W aerial photographs have positional accuracies of about 40 feet (within NMAS).
- 2) Orthophotographic products provide an excellent base map for the mapping of inland wetlands.
- 3) Of the three systems tested, Martin, Anderson, and Cowardin, respectively, the Cowardin system best fitted the needs of USGS for a national system that uses remote sensing data as a primary source of wetlands information. The definitions of the Cowardin system are easier to apply in the photointerpretation and delineation of the wetland categories, and a greater density of wetland classes can be compiled with this system.

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Figure 1: GREAT DISMAL SWAMP VEGETATIVE COVER MAP



From U.S. GEOLOGICAL SURVEY OPEN-FILE MAP 76-615

Produced by The U.S. Fish and Wildlife Service and The U.S. Geological Survey from
National Aeronautics and Space Administration Color Infrared Photography—1976

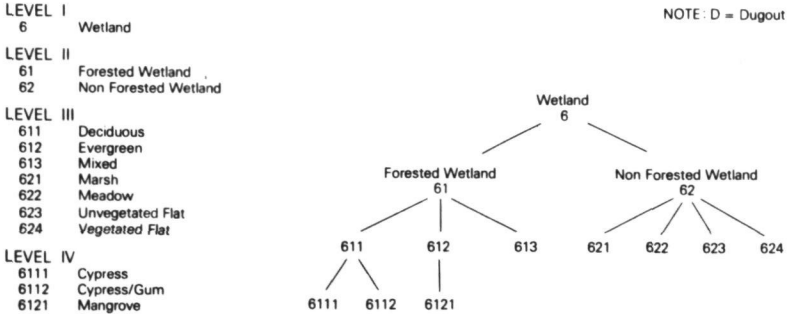
TABLE 1: Photographic criteria for mapping wetland classes and selected subclasses

<u>Class</u>	<u>Subclass</u>	<u>Mapping Criteria</u>
FW-1 Bottomland Hardwood		≥ 30% tree cover; flooded on high-water, leaves-off photographs (Feb.): not flooded on low-water leaves-off photographs (Nov.). High-water leaves-off photographs needed to separate subclasses.
	FW-1a:	Upper Bottomland Hardwood: not flooded on normal high-water photographs (Feb.).
	FW-1b:	Lower Bottomland Hardwood: flooded on normal high-water photographs (Feb.).
FW-2 Swamp		≥ 30% woody vegetation cover: flooded on high- and low-water, leaves-off photographs (Feb., Nov.).
	FW-2a:	Forested Swamp: ≥ 30% live trees.
	FW-2b:	Shrub Swamp: ≥ 30% live shrubs - sometimes narrow fringe bordering Open Water and Forested Wetland.
	FW-2c:	Dead Woody Swamp: ≤ 30% live trees, ≥ 70% dead trees (impounded water).
M-1 Marsh		≤ 30% woody vegetation cover, ≥ 70% herbaceous vegetation cover: growing season and either Nov. or Feb. photographs needed to separate subclasses.
	M-1a:	Wet Meadow: flooded in high-water spring or winter photographs (Feb.): not obviously flooded in growing season or fall photographs (Oct., Nov.).
	M-1b:	Emergent Marsh: surface water present, but hidden by persistent vegetation except on high-water photographs (Feb.) when some water may be visible.
	M-1c:	Seasonally Emergent Marsh: ≥ 10% emergent cover: flooded in high-water winter or spring photographs (Feb.), mostly dead by fall low-water photographs (Nov.), visible in growing season photographs (Oct.).
M-2 Seasonally Dewatered Flats		Visible on late growing season photographs (Oct.) or fall (Nov.) photographs at low-water, flooded on high-water photographs (Feb.). Vegetated when cover exceeds 10%.
M-3 Agriculture subject to flooding		Flooded on high-water photographs (Feb.), agriculture in growing season (Oct.) or fall (Nov.) photographs.
OW-1 Open Water		≤ 30% live tree cover: separable at low-water (Nov.) if not vegetated or associated with Marsh. Growing season photographs needed to delineate if Marsh is present.
	OW-1a:	Open Water Vegetated: surface vegetation present in growing season photographs (Oct.): ≤ 10% emergents; minimum size 0.4 ha.
	OW-1b:	Open Water Non-vegetated: no surface vegetation.

MARTIN INLAND WETLAND CLASSIFICATION

- 1 Seasonally Flooded Flat
- 2 Wet Meadow
- 3 Shallow Marsh
- 4 Deep Marsh
- 5 Open Water
- 6 Shrub Swamp
- 7 Wooded Swamp
- 8 Bog

ANDERSON INLAND WETLAND CLASSIFICATION
(Expanded to Levels III & IV by USGS)



COWARDIN INLAND WETLAND CLASSIFICATION (Modified by USGS)

- ECOLOGICAL SYSTEM
- R Riverine
 - L Lacustrine
 - D Palustrine

- CLASS AND SUBCLASS
- 1 Pools
 - 2 Riffles
 - 3 Floating-Leaved Bed
 - 4 Emergent Wetland
 - 5 Moss/Lichen Wetland
 - 6 Deciduous Shrub Wetland
 - 7 Evergreen Shrub Wetland
 - 8 Deciduous Forested Wetland
 - 9 Evergreen Forested Wetland

- WATER REGIME
- 1 Irregularly Flooded
 - 2 Regularly Flooded
 - 3 Subtidal
 - 4 Saturated
 - 5 Temporarily Flooded
 - 6 Seasonally Flooded
 - 7 Semipermanently Flooded
 - 8 Permanently Flooded
 - 9 Intermittently Flooded

- ORDER
- M Mineral
 - O Organic

- SPECIAL MODIFIERS
- i Impoundment
 - d Dugout
 - c Canal
 - ch Channelized
 - ir Irrigated
 - f Farmed

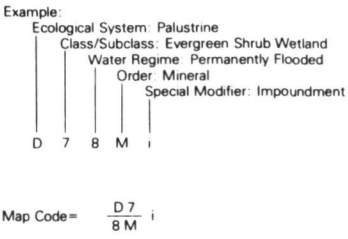


Figure 2. Wetland Classification Systems and Map Symbols

ESTIMATION OF SOIL MOISTURE
WITH RADAR REMOTE SENSING

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ABSTRACT

The radar response to soil moisture content was investigated using a truck-mounted 1-18 GHz (30-1.67 cm wavelength, respectively) Active Microwave Spectrometer (MAS) system. The sensitivity to soil moisture content and the accuracy with which it could be estimated were evaluated for both bare and vegetation-covered fields. Bare field experiments were conducted to determine the optimum radar parameters (frequency, angle of incidence range and polarization configuration) for minimizing the response to surface roughness while retaining strong sensitivity to moisture content. In the vegetation-covered case, the effects of crop type, crop height and row direction relative to the radar look direct were evaluated.

1. INTRODUCTION

The ability to monitor soil moisture variations from a space platform can be considerably useful in a variety of hydrological, agricultural and meteorological applications including crop yield prediction, flood forecasting, runoff prediction for assessing watershed yield and planning and reservoir management. One of the key requirements of the majority of the above applications is timeliness; the success of crop yield models depends on the availability of soil moisture information during critical periods in the growth cycle, forecasting floods requires knowledge of the spatial and depth distribution of soil moisture content particularly before, during and after heavy rainfall activities or rapid snow melt, and similar conditions are imposed by other water resources applications. With regard to timeliness, radar has two major advantages over optical and thermal infrared sensors: a) radar is nearly weather independent and b) radar is time-of-day independent since it provides its own source of (known) transmitted energy. Moreover, radar can provide spatial resolutions from spacecraft altitudes compatible with the needs of water resources applications.

Due to the large difference between the magnitude of the dielectric constant of dry soil and that of water in the microwave part of the spectrum, it has long been postulated that radar should be very responsive to soil moisture content. The first quantitative airborne confirmation of such a behavior was made with a 13.3 GHz NASA/JSC scatterometer which was flown in June, 1970 over an agricultural test site near Garden City, Kansas [1]. During the flight, several of the fields observed by the scatterometer were undergoing irrigation. In each case, the scatterometer output indicated a sharp change as the scatterometer flew between the sections under irrigation and the sections not yet wetted.

In general, radar backscatter from terrain is a function of the terrain geometrical and electrical (dielectric) properties. For a vegetation covered surface, the backscatter includes contributions by the vegetation and the underlying soil. The relative effects of roughness and moisture content on the return and the relative contribution by the vegetation compared to the contribution by the soil and the effect of attenuation by the vegetation, all these

factors are strongly influenced by the choice of the radar parameters: a) frequency (or wavelength), b) angle of incidence (relative to nadir) and c) polarization. An intensive program was initiated at the University of Kansas in 1971 to determine the optimum radar parameters for sensing soil moisture content of bare and vegetated terrain. This paper represents a review of the present status of the program.

2. SCATTERING COEFFICIENT

The backscatter power received by a radar viewing a cell of area A in the direction θ (relative to nadir) is given by:

$$P_r = \left(\frac{P_t G_t G_r \lambda^2 A}{(4\pi)^3 R^4} \right) \sigma^\circ$$

where,

- P_t = transmitted power
- G_t and G_r = transmit and receive antenna gain, respectively
- λ = signal wavelength
- R = range to the cell A
- σ° = scattering coefficient, m^2/m^2

P_t , G_t , G_r and λ are usually known, while A and R are calculated from the radar signal waveform parameters (such as pulse width) and the processing algorithms used by the system. Thus, σ° is the only parameter relating the terrain backscatter characteristics to the observed received power. Because σ° usually exhibits a wide dynamic range as a function of angle of incidence, it is usually expressed in decibel (dB) units.

3. SOIL MOISTURE RESPONSE

The University of Kansas Microwave Active Spectrometer (MAS) was used to acquire radar backscatter data from several crop types over the growing seasons of 1972-1976. In general, it was observed that the backscattering coefficient expressed in dB, $\sigma^\circ(\text{dB})$, varies approximately linearly with soil moisture content m , expressed in g/cm^3 . As an initial evaluation of the masking effects of the vegetation as a function of microwave frequency and angle of incidence, the radar sensitivity to soil moisture content $S = d\sigma^\circ(\text{dB})/dm$ (which is the slope of the linear regression line between $\sigma^\circ(\text{dB})$ and m) was calculated using data acquired from a variety of crop types including corn, milo, wheat, alfalfa, and soybeans for a wide range of growth conditions. Figure 1 presents S as a function of frequency between 4 and 18 GHz at several angles of incidence (relative to nadir). The decrease in S with frequency is attributed to the increase in attenuation by the vegetation. The decrease in S with angle of incidence is attributed in part to the increase in vegetation biomass along the path of the signal to the soil surface and back up to the radar receiver and in part to the decrease in sensitivity to soil moisture of the soil backscattered component itself, as will be shown later for the bare soil case. The behavior depicted in Figure 1 led us to investigate in more detail the radar response to moisture at frequencies below 8 GHz and angles of incidence between nadir and 30° .

3.1 BARE SOIL

At a given angle of incidence, microwave frequency and polarization configuration, σ° of bare soil varies with surface roughness, moisture content, and to a lesser extent, soil type. If surface roughness and soil type remain unchanged, σ° generally increases exponentially with soil moisture content.

$$\sigma_s^\circ = A e^{Bm} \quad (1)$$

where A and B are constants for a given λ , θ and polarization configuration. Expressed in dB, Equation (1) takes the form:

$$\sigma_s^\circ \text{ (dB)} = Sm + A' \quad (2)$$

where $S = 4.34 B$ and $A' = 10 \log A$. Thus, σ_s° (dB) varies linearly with soil moisture content (g/cm^3); Figure 2 illustrates this type of dependence for a relatively smooth field with a RMS height of 1.1 cm. Due to the spatial variability of the soil moisture content [2], associated with the soil moisture values of the points shown in Figure 2 is a standard deviation approximately 0.06 g/cm^3 [3]. A statistical analysis performed to evaluate the effect of this uncertainty in the value of the "ground-truth" parameter (m) on the correlation coefficient between σ_s° (dB) and m indicates that if the radar response behaves exactly as given by Equation (1), the correlation coefficient would be 0.92 [3]. Hence, the observed correlation coefficient of 0.9 is considered very high when the optimum is 0.92.

In addition to its response to moisture content, σ_s° can also exhibit large variations due to surface roughness as illustrated in Figure 3 [3]; shown are σ_s° (dB) angular responses of five fields with approximately the same moisture content but considerably different surface roughness configurations, as measured at 1.1 GHz (L-band), 4.25 GHz (C-band) and 7.25 GHz (X-band). The parameter used to describe surface roughness is RMS height. The five fields covered a range of roughness from 1.1 cm RMS height (approximately 2.5 cm peak-to-peak variation) to 4.1 cm RMS height (12 cm peak-to-peak variation). Figure 3 provides three important pieces of information:

- The variation due to surface roughness decreases with frequency; at $\theta = 30^\circ$, for example, the spread in the value of σ_s° (dB) between the smoothest and roughest fields is about 22 dB at 1.1 GHz, 11 dB at 4.25 GHz and 8 dB at 7.25 GHz.
- At each frequency, a narrow range of θ exists over which the variation due to surface roughness is small. This range is centered around 7° at 1.1 GHz, 10° at 4.25 GHz and 15° at 7.25 GHz.
- For a given surface roughness, σ_s° (dB) exhibits a sharper decay with angle of incidence as the frequency is lowered. Thus, an error in surface slope would result in a larger error in the estimate of moisture content at 1 GHz, for example, compared to 4 GHz [3].

The radar response to soil moisture and surface roughness of bare fields was investigated in 1974 at a test site in Texas [4] and again in 1975 in Kansas [3]. A major difference between the two experiments was soil texture; the soil observed in 1974 contained 49 percent clay in contrast to 17 percent clay in the 1975 soil. The objective of the experiments was to specify sensor parameters at which σ_s° (dB) is both highly correlated to soil moisture content and independent of surface roughness. Hence, the correlation coefficient between σ_s° (dB) and m and associated sensitivity were calculated (with all fields included) at each angle/frequency/polarization configuration for the 1974, 1975 and combined 1974/1975 data sets. The results, a sample of which is shown in Figure 4, indicate that:

- a) In each of the three cases, the same frequency/angle combination provided the highest correlation, namely 4.25 GHz/10° (the actual frequencies used in 1974 and 1975 were somewhat different; in each case, however, one frequency was used in the 4-5 GHz band -- 4.75 GHz in 1974 and 4.25 GHz in 1975 -- and that was the frequency chosen as optimum over the 1-8 GHz band on the basis of correlation with moisture content).
- b) Among the three linear polarization combinations, HH was slightly better than HV and VV in terms of sensitivity to soil moisture.
- c) The sensitivity S decreases with θ which suggests that it would be more desirable to operate at angles as close to nadir as possible, while retaining independence of roughness.
- d) The sensitivity S increases with frequency, particularly between 1 GHz and 5 GHz.

Figure 5 depicts the 1974 and 1975 σ_s° (dB) response to soil moisture at the optimum radar parameters with all surface roughness configurations included in the analysis. The combined 1974 and 1975 data sets provide a correlation coefficient of 0.83. Although the value of the correlation coefficient is statistically very significant (especially when compared to an optimum possible of 0.92), the slopes of the regression lines corresponding to the 1974 and 1975 data sets are different. In a study of the microwave emission from soils as a function of moisture content, Schmugge et al. [5] observed different sensitivities to soil moisture for different soil types. By converting moisture content to percent of field capacity mFC, they were able to incorporate the effect of soil type in the brightness temperature response to moisture content. A similar approach was used herein as shown in Figure 6. Conversion of moisture content to percent of field capacity does not provide any substantial improvement in the magnitude of the correlation coefficient, but does provide almost identical regression lines. This observation suggests that the radar dependence on soil texture can be removed by expressing moisture content in units of percent of field capacity which incorporates the textural constituency of the soil. From a user's point of view, percent of field capacity is a better input to crop yield and hydrologic models than volumetric moisture content since it eliminates the need to know soil type.

The accuracy with which a radar system can estimate moisture content was evaluated by conducting a classification test. The total moisture range was divided into n intervals, with an approximately equal number of points per interval, and then a linear Bayesian classifier was applied to the data. The classification test was run for values of n between 2 and 7 at each of several frequency/angle combinations. For each value of n, 4.25 GHz/10° provided the highest probability of correct classification. Figure 7 shows the results of the classification analysis at 4.25 GHz. The solid curve represents the probability of correct classification using the mean value of the in-situ measured soil moisture content while the dashed curve represents the classification probability with the spatial variability of soil moisture accounted for. That is, the moisture content was allowed to take any value within + 1 standard deviation around the mean. The results are indeed very encouraging; the n = μ case provides a probability of correct classification of 83 percent which is far superior to the current capabilities of any of the conventional meteorological methods as well as to the capabilities of optical and thermal infrared sensors, even when unhampered by cloud cover.

3.2 VEGETATION-COVERED SOIL

If the vegetation and soil backscatter components are assumed to add incoherently, the backscattering coefficient of the canopy (vegetation + soil combination) can be expressed as:

$$\sigma_C^\circ = \sigma_V^\circ + \tau \sigma_S^\circ \quad (3)$$

$$= \sigma_V^\circ = \tau A e^{Bm} \quad (4)$$

where σ_V° is the vegetation scattering coefficient and τ is the two way power transmission coefficient of the vegetation canopy. Unlike the bare soil case, conversion of σ_C° to dB scale does not yield a linear response with m . Comparison of bare soil and vegetation-covered σ° responses to m indicates that σ_V° becomes very small in comparison to the second term in Equation (4) for $m \geq 0.20$ g/cm³. Hence, as a first order evaluation of the σ_C° response to m , linear regression analyses were conducted involving σ_C° (dB) and m for several crops combined as well as for each crop on an individual basis. The results of the linear regression analyses are summarized in Table 1.

TABLE 1. LINEAR CORRELATION COEFFICIENT BETWEEN σ_C° AND MOISTURE CONTENT IN THE TOP 1 cm OF THE SOIL, $\theta = 10^\circ$, POLARIZATION = HH.

COVER	1.5 GHz	4.25 GHz	7.25 GHz
Bare Soil	0.69	0.86	0.77
Wheat	0.81	0.80	0.64
Corn	0.85	0.72	0.69
Soybeans	0.90	0.87	0.81
Milo	0.90	0.88	0.86
Corn, Soybeans and Milo	0.49	0.65	0.51
Corn, Soybeans Milo & Wheat	0.51	0.55	0.48

Although it is noted that the 1.5 GHz data provide slightly better correlations than the 4.25 GHz data for single-crop observations, the effects of row orientation relative to the radar look direction can cause substantial reduction in the accuracy of the soil moisture estimate at 1.5 GHz, whereas the 4.25 GHz and 7.25 GHz responses are practically unaffected [3]. The data used for generating the results given in Table 1 included only measurements acquired with the radar look direction within $\pm 45^\circ$ of pointing parallel to the rows. Figure 8a presents the correlation coefficient between σ_C° of soybeans and m as a function of angle at three frequencies for data acquired with the radar look direction approximately (within $\pm 45^\circ$) parallel to the rows. For comparison, Figure 8b presents the correlation coefficient based on all the data acquired from soybeans (including some with the radar look direction perpendicular to the row direction). Over the 0° to 20° angular range, the correlation coefficients at 4.25 GHz and 7.25 GHz are approximately the same in both cases (figure 8a and 8b), but at 1.5 GHz, the correlation coefficient shows a fast decrease with angle due to the row orientation effect. This effect is not attributed to the vegetation cover, it is attributed to the row spacing period used in planting row crops (typically 96 cm for corn, milo and soybeans) relative to the radar wavelength. At 1.5 GHz the wavelength is 20 cm which is much closer to the 96 cm spatial wavelength of the soil row pattern than the 7 cm wavelength corresponding to 4.25 GHz. Hence, the same conclusion arrived at for the bare soil case applies also for the vegetation-covered case, namely that the optimum radar parameters for soil moisture determination are: frequency in the 4-5 GHz range, 7° - 17° angle of incidence range and HH polarization.

4. CONCLUSIONS

In addition to its inherent cloud-independence and time-of-day independence qualities, radar can provide soil moisture information for both bare and vegetation-covered fields provided its system parameters are properly chosen. Moreover, its performance as a soil moisture mapper can be significantly enhanced if auxiliary information on crop type is made available by an independent sensor such as MSS scanners (under clear sky conditions) or an imaging radar operating in the 8-18 GHz band at angles of incidence higher than 40° [6].

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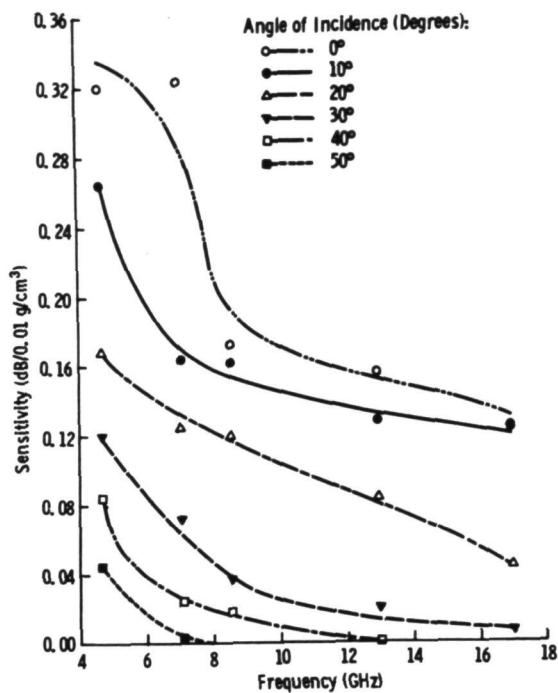
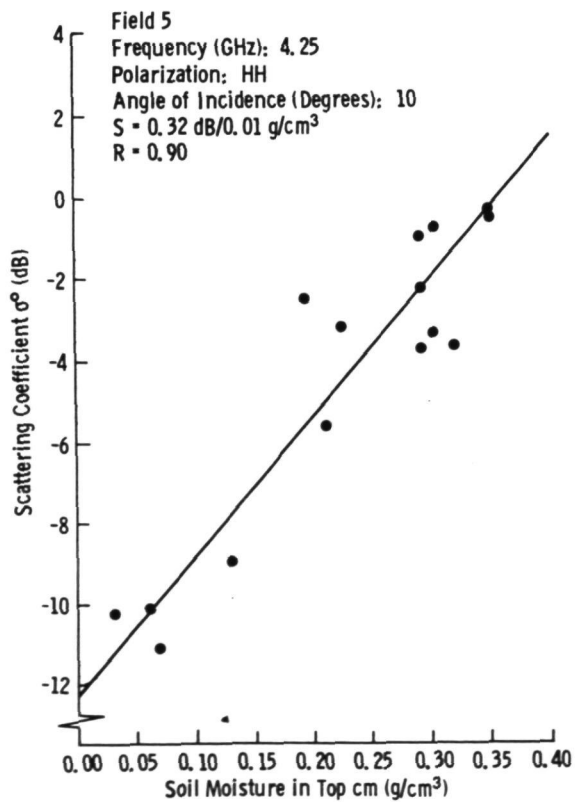


Figure 1. Radar sensitivity to soil moisture content of vegetated fields (corn, milo, soybeans and alfalfa) as a function of microwave frequency.

Figure 2. Scattering coefficient of a smooth bare soil field as a function of moisture content.



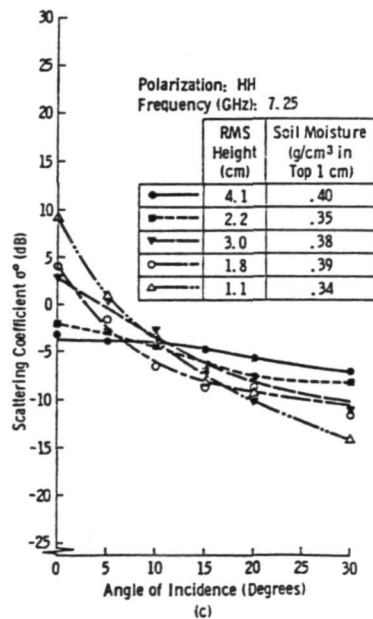
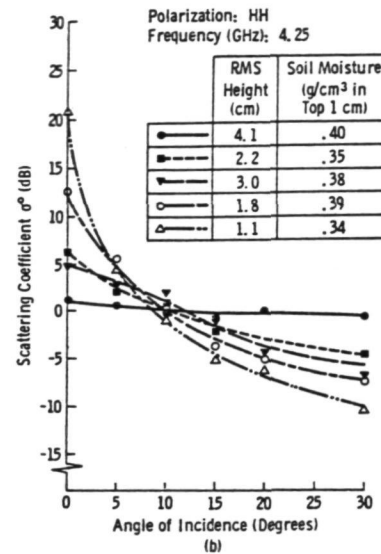
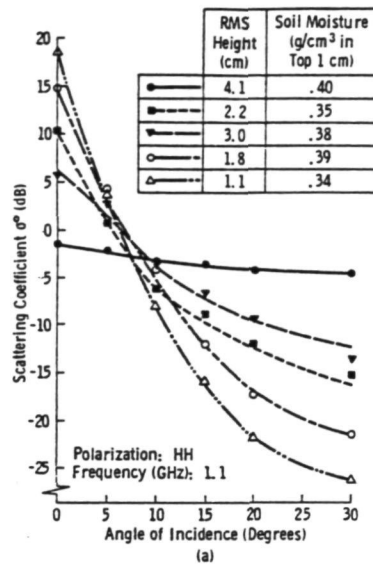


Figure 3. Angular response of scattering coefficient for the five fields for high levels of moisture content at (a) L-Band (1.1 GHz), (b) C-Band (4.25 GHz), and (c) X-Band (7.25 GHz). 1975 soil moisture experiment.

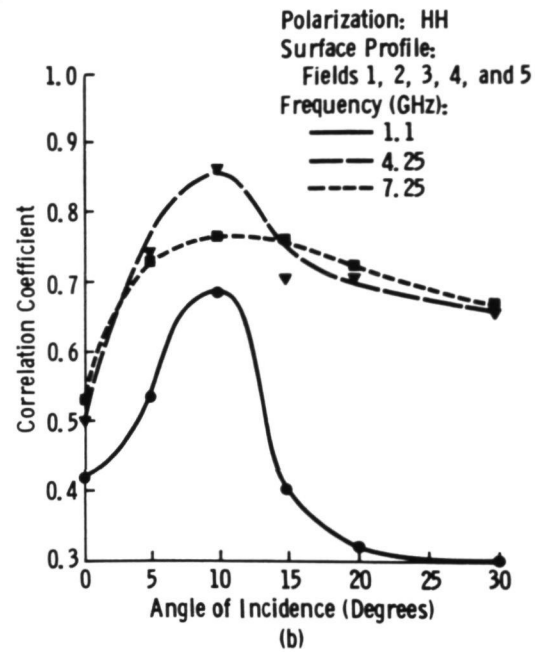
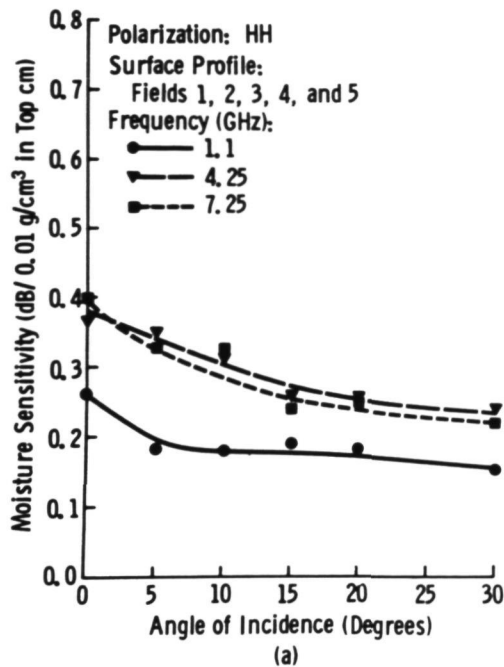


Figure 4 (a) Moisture sensitivity and (b) correlation coefficient plotted as a function of angle of incidence for all five surface roughnesses combined for 1975 data.

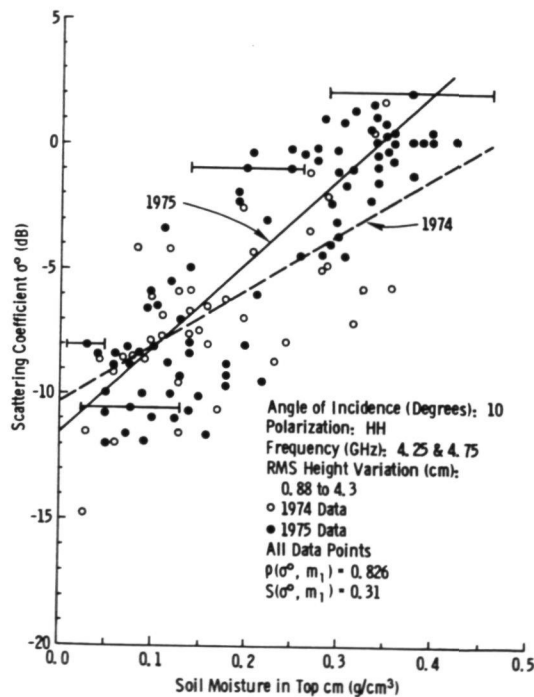


Figure 5. Backscattering coefficient as a function of volumetric moisture content in the top 1 cm of the soil. The indicated correlation coefficient ρ and sensitivity S are for the combined 1974 and 1975 data sets.

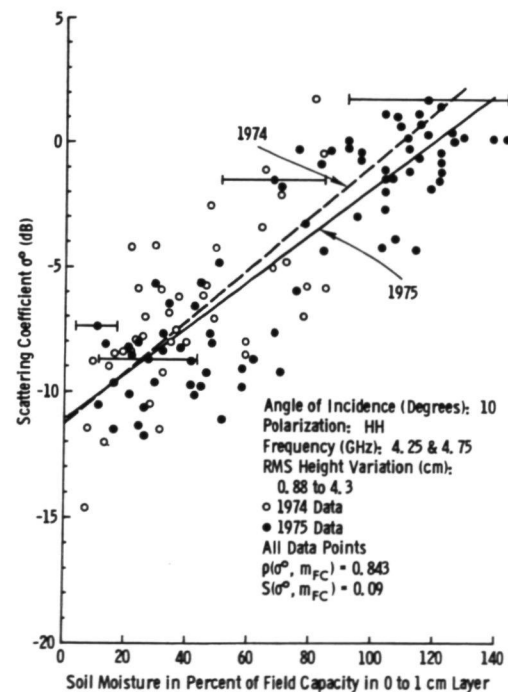


Figure 6. Backscattering coefficient as a function of percent of field capacity in the top 1 cm of the soil. The indicated correlation coefficient ρ and sensitivity S are for the combined 1974 and 1975 data sets. Same as Figure 5.

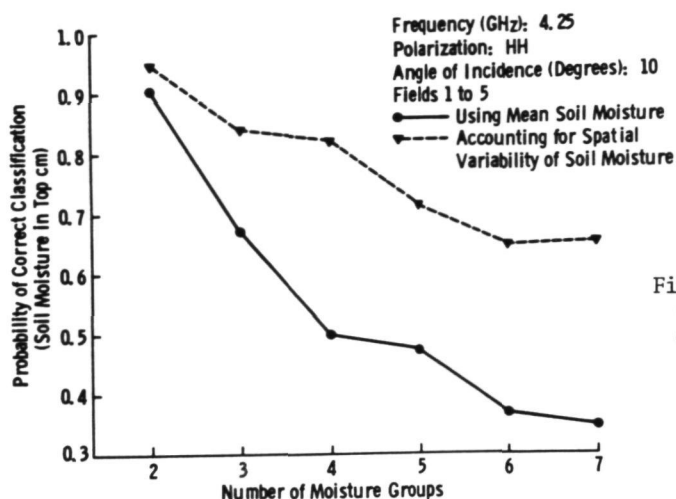


Figure 7. The probability of correctly classifying soil moisture plotted as a function of moisture groups.

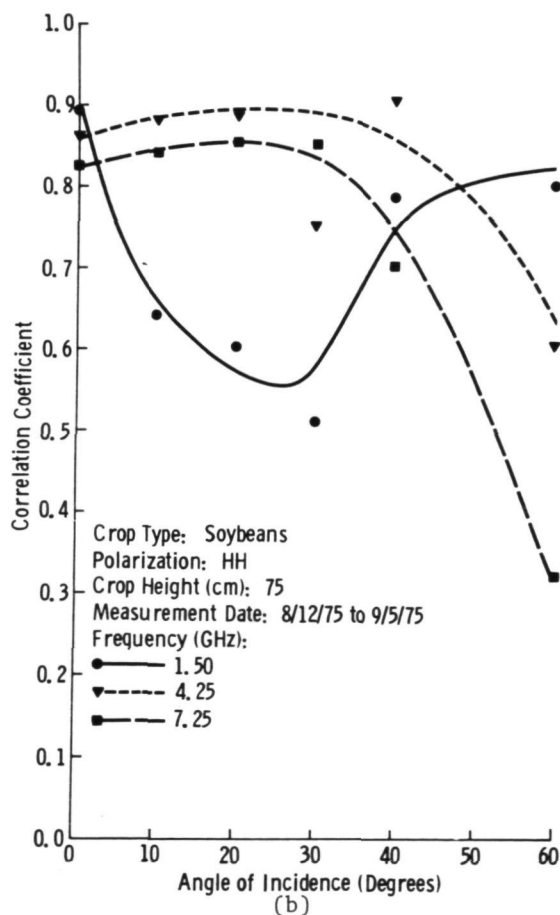
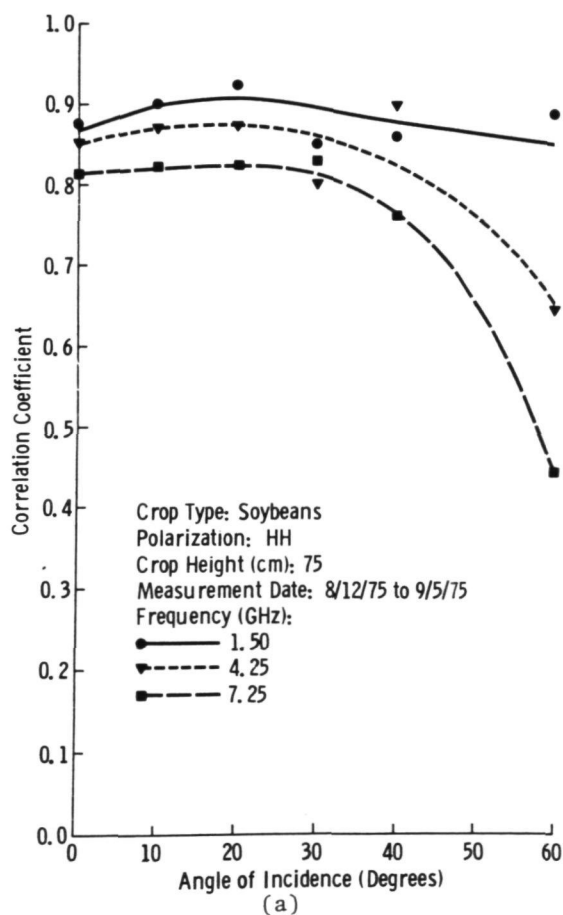


Figure 8. Correlation coefficient between backscattering coefficient and soil moisture for fields planted with soybeans at three microwave frequencies with (a) data limited to radar look direction within $\pm 45^\circ$ of looking parallel to the rows and (b) data in all look directions included.

QUANTIFICATION OF SOIL MAPPINGBY DIGITAL ANALYSIS OF LANDSAT DATA*

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ABSTRACT

Soil survey mapping units are designed such that the dominant soil represents the major proportion of the unit. At times, soil mapping delineations do not adequately represent conditions as stated in the mapping unit descriptions. Digital analysis of Landsat multispectral scanner (MSS) data provides a means of accurately describing and quantifying soil mapping unit composition.

Digital analysis of Landsat MSS data collected on 9 June 1973 was used to prepare a spectral soil map for a 430-hectare area in Clinton County, Indiana. Fifteen spectral classes were defined, representing 12 soil and 3 vegetation classes. The 12 soil classes were grouped into 4 moisture regimes based upon their spectral responses; the 3 vegetation classes were grouped into one all-inclusive class.

Using these groupings, the spectral map was compared to a conventionally prepared soil map. Three mapping units were investigated in detail: a) Mahalasville silty clay loam, b) Reesville silt loam, 0 to 2 percent slopes, and c) Xenia silt loam, 2 to 6 percent slopes, eroded.

Results indicate that the percentage of soil mapping unit inclusions can be readily ascertained according to their soil moisture regimes and that soil complexes can be easily quantified. Thus, the composition of soil mapping units can be accurately determined.

INTRODUCTION

Soil maps depict soil conditions in a particular landscape scene with varying degrees of precision depending primarily upon the type of survey conducted and the ability of the mapper to analyze the landscape and identify the

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components of the mapping units delineated. Due to the subjective nature of soil surveys and the vast areas of land involved, it is often difficult to evaluate the accuracy of the soil surveys. Currently, field methods such as spot checking and line and point intercept transects are used to evaluate the composition of mapping units. (1) Various studies (2,3,4) to determine mapping unit composition suggest that many delineations do not adequately represent conditions as stated in the mapping unit descriptions. Also, many separations on a soil map often represent soil complexes rather than taxonomic units with minor inclusions as indicated. A study was undertaken to determine the feasibility of using digital analysis of Landsat multispectral scanner (MSS) data as a means of accurately describing and quantifying soil mapping unit composition. This paper examines three distinctly different soil mapping units, comparing their composition as described by conventional field mapping techniques and digital analysis of Landsat MSS data.

A 430-hectare tract located in Clinton County, Indiana was selected as the study area. Soils in this area developed from loess deposited over glacial till derived from the late Wisconsin glaciation and localized lacustrine deposits. The surface topography ranges from 0 to 6 percent slope but the slopes are commonly less than 2 percent.

Three soil mapping units were investigated in detail: a) Mahalasville silty clay loam, b) Reesville silt loam, 0 to 2 percent slopes and c) Xenia silt loam, 2 to 6 percent slopes, eroded. The Reesville and Xenia soils were developed in the loess over glacial till and the Mahalasville soil in the lacustrine deposits. The soils of this area had previously been mapped using conventional techniques by USDA/Soil Conservation Service (SCS) personnel as part of an on-going progressive survey.

DATA

Landsat-1 MSS data collected on 9 June 1973 were used as the main data source for this study. This scene was selected because the data were: a) of high quality, b) acquired when most cropland was in a bare soil state and c) free of interfering atmospheric and surface conditions (i.e., clouds, haze and standing water). However, Clinton County had received approximately 2.90 inches of precipitation in the week prior to the Landsat overpass.

The Landsat MSS data were geometrically corrected (i.e., rotated, deskewed and rescaled to a scale of 1:20,000) (5), and registered to ground control points selected from U.S. Geological Survey 7½ minute topographic quadrangle maps. These procedures produced a data set of an exact scale of 1:20,000 with points in the data registered to their exact ground position. The aerial photography and field sheets used by the USDA/SCS personnel are also at a scale of 1:20,000. These matching scales allowed for convenient comparisons between the conventionally developed soil map and the spectral soil map derived from computer-aided analysis of Landsat MSS data.

PROCEDURES

Landsat MSS data covering the study area was input into a clustering algorithm program. This algorithm divided the MSS data into groups of sample points of similar spectral characteristics. A statistics processor was utilized to calculate the mean relative reflectance values and covariance matrices for each of these individual cluster groupings. Cluster groupings were either deleted, retained or combined based upon their statistical separability characteristics. This procedure indicated that there were 15 spectrally separable classes within the study area. The statistics developed on each of these 15 classes were used by computer-implemented pattern recognition techniques as implemented by LARSYS (6) and a maximum likelihood Gaussian classifier to assign each of the data points to one of the 15 spectrally separable classes.

A ratio ($A = \frac{V}{IR}$)* and the summed response (total magnitude of the relative intensity values of all four Landsat bands) calculated for each spectral class were used to identify 12 soil and 3 vegetation classes within the 15 spectral classes.

After classification, these classes were grouped into four major soil classes and one all-inclusive vegetation class. Each major soil class was assigned to one of four soil moisture regimes based upon the magnitudes of their respective summed responses (Table I). The class with the highest total reflectance represented moderately well drained soils; the class with the lowest reflectance represented poorly drained soils. These groupings were verified by detailed field checking.

An alphanumeric spectral map delineating the 12 soil and 3 vegetation classes was produced at a scale of 1:20,000. Field checks were conducted to evaluate the agreement between the conventionally developed soil map and the spectral soil map. Field observations included a) precise location of the three mapping units on both types of soil maps, b) notation of the various soil types and their respective moisture regimes included in the three mapping units and c) notation of the boundaries (agreements and disagreements) of the three mapping units and of their individual soil components.

RESULTS

The conventionally prepared soil map of the study area and the enhanced boundaries of the 1) poorly drained Mahalasville, 2) moderately well drained Xenia and 3) somewhat poorly drained Reesville mapping units are shown in Figure 1. For comparative purposes the three mapping units as delineated on the conventional soil map were superimposed upon the spectral soil map (Figure 2). Distinct boundary differences existed between the two maps. Also, significant inclusions not delineated on the conventionally prepared soil map were noted on the spectral soil map. In all cases, the spectral map identified inclusions within each mapping unit that had different drainage characteristics than were identified by the named mapping unit. For example, significant portions of the moderately well drained Xenia mapping unit were shown to be poorly and somewhat poorly drained according to the computer classification. Field checks of a major portion of the questionable areas revealed the spectral classification to be correct.

Statistics derived from the spectral classification of the study site (Table II) indicate that 51 percent of the Mahalasville mapping unit is appropriately classified as poorly drained. The majority of the other 49 percent of the mapping unit was classified as very poorly and somewhat poorly drained. Similarly, the spectral classification indicates that 46 percent of the Reesville and 30 percent of the Xenia mapping units were appropriately classified as the named mapping unit. Exclusive of vegetation the remainder of the Reesville mapping unit was classified as poorly and moderately well drained. Similarly, the remainder of the Xenia mapping unit was classified as poorly and somewhat poorly drained. In both the Reesville and Xenia mapping units contrasting inclusions constituted a large enough percentage of the named unit to justify additional separations or the mapping of a soil complex.

CONCLUSIONS

Digital analysis of Landsat multispectral scanner data can provide detail and definition of soil features not readily discernible through visual interpretation of Landsat imagery. It is apparent from this study that digital

*where V is the relative intensity of the mean spectral responses of the visible wavelengths {(0.5 to 0.6 μ m) + (0.6 to 0.7 μ m)} and IR is the relative intensity of the mean spectral response of the reflective infrared wavelengths {(0.7 to 0.8 μ m) + (0.8 to 1.1 μ m)}

analysis of Landsat MSS data can provide quantification of soil mapping. The percentage of soil mapping unit inclusions can readily be ascertained according to their soil moisture regimes, and soil complexes can be easily quantified. Thus, the composition of mapping units can be accurately determined.

The use of digital analysis of Landsat data as a mapping tool to quantify soil mapping unit compositions should greatly increase the accuracy of soil surveys. By utilizing this quantification procedure, other aspects of the soil survey, such as soil interpretations for urban uses, may be also greatly enhanced.

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TABLE I. RELATIVE SPECTRAL RESPONSES OF GROUPED CLASSES.

<u>Spectral Map Symbol</u>	<u>Drainage Class</u>	<u>Range of Summed Response</u>	<u>Range of Ratio A</u>
/	Moderately Well	184.47-218.13	1.03-1.33
+	Somewhat Poorly	162.47-176.20	1.32-1.35
X	Poorly	136.31-151.05	1.16-1.35
M	Very Poorly	118.78	1.40
Blank	(Vegetation)	140.93-150.49	0.59-0.74

TABLE II. COMPOSITION OF SOIL MAPPING UNITS.

<u>Characteristics of Named Mapping Unit</u>				
<u>Mapping Unit</u>	<u>Spectral Class</u>	<u>Internal Drainage Class</u>	<u>Size of Mapping Unit (Hectares)</u>	<u>% and Area (Hectares) of Unit Represented by Named Series</u>
Mahalasville Silty clay loam	X	Poorly	47.65	51.40% 24.49
Reesville silt loam, 0 to 2 percent slopes	+	Somewhat Poorly	51.21	46.08% 23.60
Xenia silt loam, 2 to 6 percent slopes, eroded	/	Moderately Well	13.36	30.00% 4.01

Percent and Area (Hectares) of Inclusions within the Above
Mapping Units Identified by Drainage Classes

<u>Spectral Symbol</u>	<u>Very Poorly Drained</u>	<u>Poorly Drained</u>	<u>Somewhat Poorly Drained</u>	<u>Moderately Well Drained</u>	<u>(Vegetation)</u>
X	21.49% 10.24	--- ---	17.75% 8.46	9.34% 4.45	.02% ---
+	.88% 0.45	20.00% 10.24	--- ---	18.26% 9.35	14.78% 7.57
/	--- ---	16.67% 2.23	40.00% 5.34	--- ---	13.33% 1.78

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FIGURE 1. CONVENTIONAL SOIL MAP INDICATING THE
(1) MAHALASVILLE, (2) XENIA, AND
(3) REESVILLE MAPPING UNITS.

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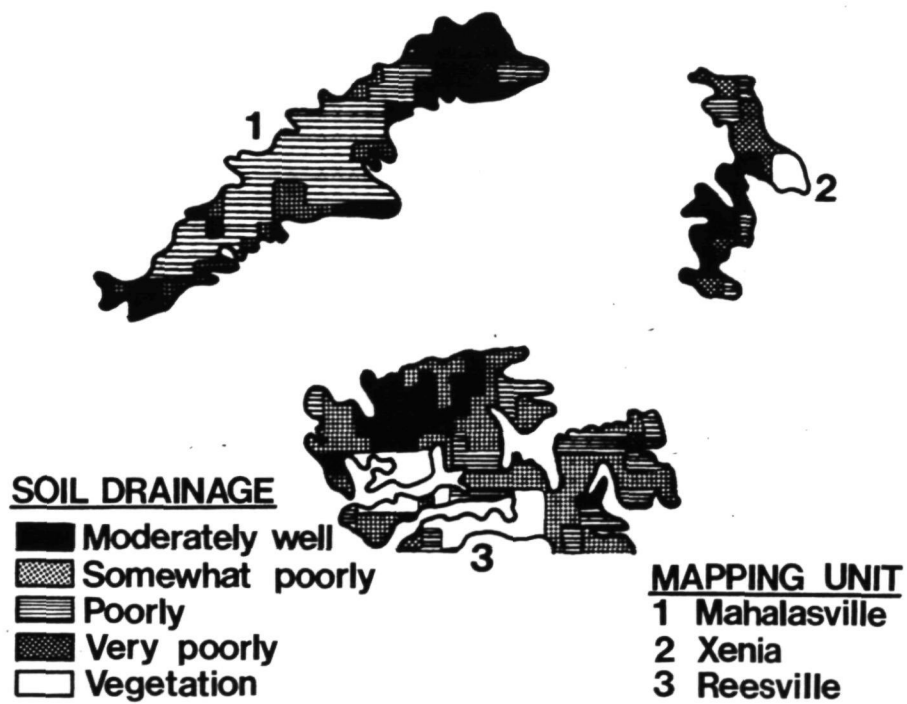


FIGURE 2. CONVENTIONALLY DELINEATED MAPPING UNITS SUPERIMPOSED UPON THE SPECTRAL SOIL MAP.

APPLICATIONS OF THERMAL INFRARED IMAGERY FOR ENERGY CONSERVATION AND ENVIRONMENTAL SURVEYS

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ABSTRACT

This report documents the results of a U.S. Government interagency study designed to determine the feasibility of using remote sensing technology to reduce the number of manhours currently required for energy conservation and environmental surveys. The survey procedures, developed during the winter and summer of 1976, employ color and color infrared aerial photography, thermal infrared imagery, and a handheld infrared imaging device. The resulting imagery was used to detect building heat losses, deteriorated insulation in built-up type building roofs, and defective underground steam lines. The handheld thermal infrared device, used in conjunction with the aerial thermal infrared imagery, provided a method for detecting and locating those roof areas that were underlain with wet insulation. In addition, the handheld infrared device was employed to conduct a survey of a U.S. Army installation's electrical distribution system under full operating loads. This survey proved to be a cost-effective procedure for detecting faulty electrical insulators and connections that if allowed to persist could have resulted in both safety hazards and loss in production.

The color and color infrared aerial photography aided in the interpretation of the thermal infrared imagery, provided a baseline of environmental conditions for future comparison, and provided a means to detect environmental problem areas.

The report also discusses the most efficient image scales and time of image acquisition, and concludes that remote sensing technology can reduce the cost and time required to conduct energy and environmental surveys.

INTRODUCTION

Our country's emphasis on energy conservation projects and environmental assessment programs has not been accompanied by adopting improved technological advances. The U.S. Army Intelligence and Security Command* (USAINSCOM) military installations as well as other Government installations are currently facing this emphasis with less resources than in the past. This paradox is the result of inflated labor and material costs, significant increases in utilities cost, and a reduced in-house work force.

Based upon experience of personnel within USAINSCOM, a program was developed that would use remote sensing aerial reconnaissance procedures coupled with ground surveillance for energy losses and environmental monitoring of military installations. In this regard, USAINSCOM contacted other Government research and development organizations for participation. As a result, the participating agencies in this program included the Environmental Projection Agency, Environmental Photographic Interpretation Center (EPIC), Warrenton, VA; U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA; and U.S. Army Intelligence and Security Command, Arlington, VA. Also, the Health Service Command's Health and Environmental Service (H&E), Fort Myer, VA, and the Health and Environment Activity (HEV), Fort Belvoir, VA, contributed in this joint pilot project.

*As of 1 January 1977, the U.S. Army Security Agency is now part of the U. S. Army Intelligence and Security Command.

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OBJECTIVES. The purpose of this interagency endeavor was to demonstrate the feasibility and to determine the requirements for an environmental and operational assessment of U.S. Army installations. The major areas of interest investigated included, but were not restricted to, the following: grounds and vegetation including erosional features, utilities and structures, and sanitary/health considerations.

INSTALLATIONS. Two installations were selected for the survey: Vint Hill Farms Station, near Warrenton, VA, and Arlington Hall Station, Arlington, VA. Both of these stations are under the command of USAINSCOM and are representative of a typical rural and urban environment, respectively.

Vint Hill Farms Station. Vint Hill Farms Station is situated in the northeast corner of Fauquier County, VA, along State Route 215, two miles from the junction of State Route 215 and U.S. Route 15. The installation contains 720 acres of land distributed among the following general categories: improved grounds - 147 acres, semi-improved grounds - 362 acres, unimproved grounds - 116 acres, and forest lands - 95 acres.

The major sources of air emission at Vint Hill Farms Station are a 15.5 Million British Thermal Unit (MBTU) natural gas-fired heating plant, 472 small natural gas-fired heating units, gasoline storage tanks totaling 42,000 gallons capacity, and two refuse incinerators. Waste water from the installation is processed in two onsite sewage treatment plants.

Arlington Hall Station. Arlington Hall Station is situated within a residential area 5 miles from Washington, D. C., in the central part of Arlington County, VA, just south of U.S. Route 50. The installation is north of State Route 244 (Columbia Pike) and west of State Route 120 (Glebe Road). The installation contains 87 acres of land, of which approximately 35 acres are improved grounds; buildings occupy approximately 10 acres and parking, 25 acres. There are no water bodies on the post; storm drainage flows through a system of drains into Doctor's Branch Creek, but sewage wastes are disposed of through the Arlington County sanitary sewer system.

SCHEDULE. To determine seasonal variabilities, the investigation was conducted during both the winter (17 March to 6 April) and summer (28 July to 27 August) seasons of 1976.

TECHNICAL APPROACH

AERIAL IMAGERY. Three types of aerial imagery were acquired during the winter and summer phases of the program. The imagery included two types of aerial photography (color* and color infrared**) and thermal infrared scanner imagery.

The aerial photography was employed primarily to document environmental conditions as they existed during the study, provide a baseline of physical features at the two installations, and provide a means of updating the installation's basic engineering site maps.

Color infrared aerial photography is sensitive to reflected energy in both the visible and near infrared regions of the electromagnetic spectrum. Under certain conditions, this film is capable of detecting diseased and/or physiologically stressed vegetation, often before it can be detected from ground observation. This capability relies on a difference in the reflectivity that usually exists between healthy plants and those growing under some type of stress. The changes in reflectivity are related to the sensitivity of chlorophyll and internal foliar geometry to metabolic disturbances. As chlorophyll content decreases and internal foliar geometry changes, reflectance of the stressed plant tends to increase in the visible portion of the spectrum and decrease in the near infrared region.*** On a correctly exposed color infrared aerial photograph, these opposing reflectance changes initially create a magenta pattern with the color shifting to yellow and green as the stress increases. The healthy vegetation will image as light red or pink. There are a number of factors, however, that can affect the reflectance characteristics of vegetation other than disease or physiological stress even between plants of the same species. These factors include leaf thickness, orientation, and surface properties. This film has been used successfully in the past to detect diseases, the effects of insect attacks, nutrient deficiencies, drought, high soil salinity, and propane or natural gas leaks.

*Kodak Aerochrome MS, Type 2448.

**Kodak Aerochrome Infrared, Type 2443.

***E. B. Knipling, "Physical and Physiological Basis for the Reflectance of Visible and Near Infrared Radiation from Vegetation," Remote Sensing of the Environment, Vol. 1, pp. 155-159.

The two most important concepts to understand when interpreting thermal imagery are "blackbody" and "emissivity." A blackbody is defined as a perfect absorber of all incident energy with zero reflection. A theoretical blackbody, also, is a perfect radiator of energy and emits the maximum amount of energy possible for its temperature. Emissivity is the ratio of the energy radiated from a material to that of a perfect radiator or blackbody. The highest value of emissivity is unity (1.0), which occurs from a theoretical blackbody. On the other hand, a body that reflects all incident energy and absorbs or radiates none has an emissivity of zero. Carbon black is an example of a material with high emissivity. Building materials, vegetation, and terrain fall between these extremes and are termed gray bodies (table 1). When a surface such as a parking lot or roof is composed of a number of materials with each type of material having a different unknown emissivity, it is difficult to determine the absolute temperature of that surface from thermal imagery. In addition to this problem, the amount of moisture vapor in the atmosphere, wind direction, and velocity can attenuate the amount of infrared energy radiated to the airborne scanner. Normally, thermal imagery is presented to the interpreter such that light-toned patterns are represented as high temperatures, and dark or dense areas are represented as low temperatures.

TABLE 1. THERMAL RADIATION CHARACTERISTICS OF MANMADE MATERIALS

SURFACE	RADIATION	
	EMITTANCE %	ABSORPTION %
Asphalt, Black Paint	90 to 98	85 to 98
Concrete, Red, Brown, Green Paint	85 to 95	65 to 88
White Paint, Tile	85 to 95	30 to 60
Window Glass	90	4 to 40
Galvanized Steel	20 to 30	40 to 65

SOURCE: W. L. Wolfe, Handbook of Military Infrared Technology, Office of Naval Research, Department of the Navy, Washington, D. C., 1965.

BASELINE ENVIRONMENTAL SURVEY. The first requirement of an environmental survey or inventory is to establish a baseline or point of reference to which continuing environmental changes can be compared. The number and type of factors that the Facility Engineer has to monitor are specified in AR 420-10.* However, some of these specifications have to be varied according to the geographical setting of each installation. Obviously, such factors as water and air quality require that specific measurements must be obtained on the ground, but remote sensor imagery has the unique capability of documenting many of the factors that would be difficult and expensive to obtain by ground surveys. The old saying that "a picture is worth a thousand words" should be remembered here. Erosional features, vegetation mapping and vigor classification, and wildlife habitat surveys are only examples of the many environmental factors that can be monitored from aerial imagery. The ground data collection of this survey is summarized below.

Winter Phase. A survey of the water quality at Vint Hill Farms Station was conducted by the Fort Belvoir Health and Environment Activity on 18 March 1976 during the approximate time of the overflights. Water quality at Arlington Hall Station was not surveyed due to the absence of standing water and post sewage being piped to county treatment plants. Owing to equipment and time limitations, water samples were limited to the edges of the streams and lakes at Vint Hill Farms Station. The water samples were analyzed for biochemical oxygen demand (BOD), turbidity, specific conductance, apparent color, arsenic, lead, cadmium, and mercury. Temperature and pH were obtained at the time of acquisition. In addition, a survey was made of field service health and environmental conditions per AR 40-5** at both installations.

Summer Phase. The summer water quality survey was conducted in a manner similar to the one conducted during the winter phase by the Fort Belvoir Health and Environment Activity. Since each survey was conducted to determine indications of water pollutants, a point sampling method was used instead of a complete statistical sampling procedure. Care was taken, however, to sample streams where they entered and exited Vint Hill Farms Station so that the effect of the installation's runoff could be determined.

*U.S. Army, "Facilities Engineering - General Provisions, Organizations, Functions, and Personnel," Regulation 420-10, May 1975, Washington, D. C.

**U.S. Army, "Medical Services: Health and Environment," Regulation 40-5, September 1974, Washington, D. C. 1577

In addition to the water quality parameters surveyed during the winter phase, the summer phase also included total phosphates and a count of fecal coliform bacteria colonies.

ELECTRICAL SURVEY. Handheld thermal infrared imaging devices have been employed by electrical power companies for many years to identify potential problem areas. These thermal devices operate on the proven principle that there is a definite relationship between the temperature of an object and the infrared radiation emitted by the object. This equipment detects the infrared energy, converts it into video signals, and then projects the signals onto a monitor picture with the various shades of gray representing different temperature levels through a chosen temperature range. As with the aerial thermal infrared imagery, black corresponds to a colder temperature and white corresponds to a warmer temperature.

Loose or corroded connections, poor contacts, unbalanced loads, and loose bus joints introduce additional resistance into an electrical circuit causing these connections to have a temperature that is higher than normal. These "hot" connections are imaged on the thermal infrared equipment as white areas. The advantage of this survey method is that the electrical power is not interrupted during the survey.

The electrical survey starts at the point of delivery from the power company and proceeds along the main feeder lines to the final transformer, which serves a consuming facility. When the operator identifies a hot spot, the installation representative marks the location and probable cause on the installation's electrical distribution drawings.

ROOF SURVEY. The detection of moisture in flat built-up roofs with the use of handheld thermal infrared imaging instruments has proven to be one of the highest payoff applications of infrared technology. Previously, when a roof leaked and the leak could not be located easily, the entire roof was replaced. In most cases, repairing portions of a roof will correct the problem at a much lower cost than replacing the entire roof. To understand how infrared devices can be used to find wet areas in the roof, it is helpful to understand the construction of a built-up flat roof. Figure 1 is a cutaway drawing of a flat built-up roof showing the method of construction. A leak results when the moisture barrier develops a hole or tear, cracks occur due to age, or the flashings fail. When the moisture reaches the insulation through a failure of the moisture barrier or flashing, it can travel through the insulation with little interference. Interior leaks result when moisture passes through the insulation and the roof decking.

In addition to interior leaking, the wet material loses most of its insulation properties. This loss of insulation and the resulting increase in conductivity can be detected by the infrared equipment. During the winter when the building interior is heated, the wet insulation conducts heat at a faster rate than the dry insulation, thus increasing the surface temperature of the roof over the wet insulation. The infrared equipment is used to detect those portions of the roof that have a higher surface temperature.

The equipment can also be used when the building is not heated. Heat energy received from the sun will be absorbed and contained by the wet areas of insulation longer than the dry portions, thus creating a higher roof surface temperature. At night, when the heat loss by radiation is highest, those roof areas underlain by wet insulation can be detected because of their higher temperature.

After sundown, a ground infrared roof survey is more effectively accomplished in three steps. The first step is a review of the building drawings and a day inspection of the roof. The day inspection locates the obvious failures, provides general information on the condition of the roof, and enables the survey team to become familiar with the roof. In addition, safety hazards are noted since the team will have to walk the roof at night. The second step is the night infrared survey. The roof is scanned with the infrared equipment and the areas that appear to be warmer are outlined with white spray paint. Photographs are taken of the infrared image for documentation. The third step includes the documenting of the survey. Areas noted and marked with paint are sketched on the drawings.

DATA ACQUISITION

AERIAL IMAGERY.

Winter Phase. The acquisition of aerial imagery required two overflights for each of the two installations, one during the day and the other during the early morning hours. The first overflights were completed between the hours of 0430 and 0600 on 18 March 1976 at an altitude of 1,000 feet (305 meters) above the ground. During the period, three flight lines of thermal infrared imagery were acquired over Arlington Hall Station, and five flight lines were acquired over Vint Hill Farms Station with an AAS-27 thermal infrared scanner. The midday overflight was delayed because of poor weather conditions until the early afternoon of 18 March. This overflight was employed to obtain color and color infrared of both

installations at a scale of 1:2,000 simultaneously with two KC-1 cameras equipped with 6-inch (15 cm) focal length lens. With the exception of the midday overflights, weather conditions were exceptionally good for the acquisition of aerial imagery on 18 March. The air temperature was approximately -9.00C with very little air movement, and the sky was free of clouds during the predawn flights.

Summer Phase. The imagery for this phase of the study was flown on 20 and 21 July 1976 with seven flight lines of photo and infrared imagery acquired at Vint Hill Farms Station and three flight lines acquired at Arlington Hall Station. An additional flight line was obtained at Vint Hill Farms Station at a scale of 1:4,000. As with the winter phase, weather conditions prevailing during the predawn and midday flights were excellent. Although the flight parameters and aerial cameras employed during the summer phase of the study were identical to those used in the winter phase, an AAD-5 thermal infrared scanner was used on 20 July instead of the AAS-27. Both of these scanners were operated in the 8- to 14-micron region of the electromagnetic spectrum, were uncalibrated, and were employed in the direct film record mode.

GROUND TRUTH MEASUREMENTS. In order to document ground temperatures, to provide a knowledge base for interpretation of the infrared imagery, and to provide a calibrated temperature source, an intensive ground data collection procedure was conducted at each installation during the period of aerial imagery acquisition. The procedure consisted of the following functions:

<u>FUNCTION</u>	<u>EQUIPMENT</u>
Surface Temperatures	PRT-10 Radiometer
Humidity	Psychrometer
Windspeed	Thermo-anemometer
Calibrated Temperature Source*	Thermometer
Internal Building Temperatures	Thermometer

In addition, the installation's engineering drawings were available. These drawings were of roof construction, utility distribution, and general site maps.

ELECTRICAL AND ROOF SURVEY. Two types of thermal infrared equipment were employed during the roof survey. The first was a device developed by the U.S. Army Night Vision Laboratory (NVL), Fort Belvoir, VA, as a tactical night vision aid. The second was developed by the AGA Corporation of Sweden.

The NVL equipment, designated PAS-10 (figure 10), is a thermal infrared device that operates in the 3- to 5-micron range of the electromagnetic spectrum. It weighs 9 pounds, is self-contained, and is battery operated. Although developed for tactical use, it has capabilities for the inspection of utility systems and roofs. This equipment has a real-time display, but photographs of the output can be obtained by mounting a camera against the single eyepiece and obtaining a time exposure. The cost of this equipment is approximately \$30,000.

The commercial infrared AGA equipment costs in excess of \$45,000 and weighs approximately 15 pounds. It also operates in the 3- to 5-micron portion of the spectrum and requires liquid nitrogen to cool the detector. Power is provided by an external battery pack, and the detector is held separately from the chest-mounted display portion of the equipment. A camera can be mounted within the viewing shield to provide a photographic record.

WATER QUALITY. The method and equipment employed in the water quality analysis is summarized as follows:

<u>FUNCTION</u>	<u>METHOD/EQUIPMENT</u>
Temperature	Thermometer
pH	Phenol Red Indicator, Taylor Chemical Color Comparator
BOD	Standard Method No. 219**
Oxygen Uptake	Agide Modification (Winkler Method)
Cadmium, Lead	Standard Method No. 129A, Perkin-Elmer Atomic Absorption Unit/Graphic Furnace

*Three 5-foot-diameter wading pools were located at each installation and maintained at each of three temperatures by continually adding warm water.

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**American Publishing Health Association, 14th Edition, "Standard Method for the Examination of 5 Water and Waste Water," Washington, D. C., 1976.

<u>FUNCTION</u>	<u>METHOD/EQUIPMENT</u>
Arsenic	Standard Method No. 404A, B&L Spectronic 88
Apparent Color	<u>Water Analysis Handbook</u>
Total Phosphates	Spectrophotometer, Hack
Turbidity	DR 2, Turbidimeter, Hatch, Model 2100A
Conductivity	Standard Method No. 154 and 205, Beckman RC 16B2
Fecal Coliform Bacteria	Standard Method No. 909C
Dissolved Oxygen	Standard Method No. 422B. Fixed at site with manganese sulfate solution, alkali-iodine solution, and concentrated H ₂ SO ₄ . Titrated within 6 hours with sodium thiosulfate.
Mercury	Cold Vapor Technique*

DATA ANALYSIS

AERIAL IMAGERY. In summary, three types of aerial imagery were employed in the winter and summer phases of this study: Thermal infrared imagery, obtained before sunrise and again during the early afternoon; color and color infrared aerial photography, acquired within 8 hours of the thermal imagery. The color and color infrared photography in addition to providing information for the baseline environmental survey was also used to determine if temperature variations indicated on the thermal imagery were caused by standing water and to identify physical roof features such as heat vents, sky lights, and roof surface materials. The analysis of the data collected during the summer and winter phases, presented in the following paragraphs, includes three major steps: (1) Correlation of the three types of aerial image patterns; (2) Correlation and analysis of aerial image derived data with ground base measurement data; and (3) Confirmation of the results through onsite inspections by the facility engineers at each installation.

In viewing the thermal infrared imagery presented in this analysis, one should remember that the dark tonal areas represent cold surface temperatures and the light tonal areas indicate warmer temperatures. Also, the noticeable lineations that make up the thermal imagery are characteristic of optical electrical scanner imagery. All thermal imagery and photography presented in this report are fourth generation reproductions; therefore, some of the points discussed may not be evident in the illustrations.

Vint Hill Farms Station.

Figures 3 to 9. Figure 3 is a winter night infrared image of a portion of Vint Hill Farms Station showing Buildings 160 (E, figure 3); 162 (D, figure 3); 163 (K, figure 3); and 166 (A and B, figure 3). Figures 4 and 5, obtained during the summer phase, are day and predawn infrared images, respectively, and are essentially of the same area as figure 3. In general, the winter day thermal infrared imagery was of little value in this study. This was due primarily to excessive amounts of solar radiation existing during daylight hours but also to large amounts of standing water on the roofs during the time of image acquisition. Thus, the sensitivity range of the scanner was exceeded. Although figures 6, 7, and 8 are of the same area as figures 3 and 5, they are winter color** and color infrared photography and summer color infrared photography, respectively.

The roof of Building 166 (A, figure 3) and the connected utility room roof (B, figure 3), which contains a heating plant, are flat built-up roofs surfaced with similar roofing materials, tar and gravel. The utility building, however, is vented to ambient air. Ground measurements obtained at the time of image acquisition indicate that the external temperature of the utility room roof was -5.00°C, while the roof of the main portion of Building 166 was -10.00°C. This 5.00 variance in temperature between these two roofs can be seen in figure 3, A and B. The utility room roof (B, figure 3) is the warmer, indicated by its lighter tone. Ceiling temperature measurements obtained within Building 166 and the utility room were +10.00°C and +14.00°C, respectively. If the insulation value of these two roofs were the same, the utility room roof would appear as having a higher temperature, but not to the extent indicated on the imagery. Examination of the winter and color and color infrared photography did not reveal the existence of standing water on either of these roofs that would have contributed to this difference.

*Environmental Protection Agency, Office of Technology Transfer, "Methods for Chemical Analysis of Water and Wastes," Washington, D. C., 1974.

**Presented in these proceedings as black and white photographs to reduce the cost of publication.

In viewing the summer day infrared imagery (figure 4), no significant difference exists between the two roofs (A and B, figure 4). Ground temperature measurements, however, indicate a 5.0°C difference between these two roofs and a 13° to 18°C difference between these roofs and their background of grass-covered lawns. This 13° to 18°C temperature difference between the building roofs and their immediate background can be seen in figure 4.

The measured summer day temperature difference between the two roof surfaces (A and B) can be explained by the fact that the utility room roof was uninsulated, enabling solar energy to be rapidly conducted to the interior of the building. Normally, a 5°C difference in roof temperature would be within the sensitivity range of the scanner, but excessive solar radiation that exists during the day precludes the detection of small temperature differences.

The summer night thermal imagery also indicated the high thermal loss through the roof of the utility room (B, figure 5). The image, in this instance, correlated quite well with ground temperature measurements, which established the presence of a 3°C difference in temperature between the roofs of the utility room and Building 166 (A and B, figure 5). The detection of this small temperature difference demonstrates the effectiveness of night versus day acquired infrared imagery. It also demonstrates that on a clear, cold, windless night the roofs of insulated buildings can be colder than both the internal building temperature and the external ambient air temperature (A, figure 5). The influence of air temperature, with little or no wind, is not considered as important as an unobstructed sky in the energy emission process of roofs. During the time of image acquisition, the temperatures of these two buildings were as follows:

	BUILDING A (Temperature °C)	BUILDING B (Temperature °C)
Roof	17	20
Internal	22	24
External Ambient	20	

The roof of Building A has a colder surface temperature than B because the heat flow from the building interior to the roof surface is retarded by insulation. In Building B, the internal to external heat flow to the roof is largely unrestricted; therefore, its temperature would be expected to be at or near that of the ambient air.

The large warm area (C, figure 3) is the discharge of a hot water hose that was employed to maintain three temperature reference basins. These basins, used to provide a known temperature reference, appear as three small white dots to the left of C in figure 3. It was anticipated that these basins could be used with optical microdensitometry techniques to obtain quantitative temperature data from the thermal imagery. Unfortunately, the image size of these basins was too small for practical use.

During the predawn winter flight, ambient air and grass temperatures were measured at -10°C and the asphalt roadway, -8°C. These temperature variations correspond to the gray tone patterns on figure 4. The amount of grass cover and other features, such as pathways and sidewalks that produce different tones of gray on the thermal imagery, can be better visualized by viewing the color and color infrared photography obtained during the same day (figures 6 and 7).

Using aerial infrared imagery for locating entrapped moisture within roof insulation employs the same concepts as those used by the handheld infrared equipment, e.g., insulation saturated with water will hold heat for a longer period of time than dry insulation. In figure 5, the two light-toned areas marked D are areas of wet insulation previously located by the handheld infrared equipment. Based on the results of this study and the realization that major thermal energy source for this process is the sun and not internal heat loss, the time of image acquisition becomes extremely important. In figure 3, for example, the wet areas are not images for two reasons: (1) the solar radiation from the sun is less in the winter than in the summer; therefore, the entrapped moisture is not heated to the same degree as in the summer season; and (2) most important, the time of this flight was 0420 hours, which was too late for maximum temperature contrast between the dry areas of insulation and the areas with entrapped moisture.

The relationship between the gray tones on the infrared imagery and the normal variables encountered on a roof surface such as light- and dark-colored roof materials, vents, surface water, and water within the insulation is evident on Building 160 (figures 6 and 7). Roof surface water is marked as E in figures 3, 6, and 7. On the top of roofs, water or moisture images as a dark color on the color photograph (figure 6) and as a black tone on the color infrared photograph (figure 7). The temperature of most of the roof surface water has

dropped to the same temperature as the roof by early morning (time of the winter night imagery), and only the deep pools of water provide a temperature contrast (figure 3). Two things become evident from a study of this image. First, to be most effective, the infrared flights should be scheduled earlier, approximately 1900 to 2200 hours. Second, roof surfaces should be free of standing water.

Steam line heat losses were also detected on the thermal imagery. An uninsulated expansion joint in an aboveground steam line can be seen as H in figures 3, 5, and 8. Underground steam line heat losses can be seen as I and Y in figures 3 and 5. The underground steam line leading from the heating plant (J, figure 5) to Building 160 (Z, figure 6) lies under the concrete sidewalk marked I in figure 5. The steam line marked Y in figure 5 is buried approximately 30 feet and then surfaces.

The relationship between emissivity, solar radiation, different roof surfacing materials, and their resulting gray tone characteristics on thermal infrared imagery can be seen in figures 3, 4, and 5. The corresponding winter color and summer color infrared photography (figures 6, 7, and 8) presents these same characteristics in the visual and near infrared portion of the electromagnetic spectrum.

The roof surface of Building 163 (K, figure 7) is a peaked asphalt, shingle roof that is dark green in color. The tone of this roof surface and the roof of Building 162 (D, figures 4 and 5) exhibit the same thermal image tonal characteristics. Roof D is a built-up roof surfaced with gray gravel. Although there is a variance in both the reflectivity and emissivity between these two roofs, roof construction differences have caused the roof surfaces to have the same image tones.

The thermal effect of different types of roof surface materials on Building 160 is indicated by M, N, and L, figure 4. The summer color infrared photo (figure 8) depicts a lack of surface water on this roof that would affect its thermal image.

In figure 8, roofs L and M are surfaced with a light brown gravel, and roof N is surfaced with a dark gravel. The day thermal image tonal differences (L and N, figure 4) are the result of varying amounts of thermal absorption based on light versus dark materials. The tonal differences of roofs L and M, figure 4, are due to differences in roof construction (as determined from the engineer drawings). Roof L has a dropped insulated ceiling that is adequately ventilated, and roof M (adjacent to N) has a dropped insulated ceiling that is not adequately ventilated. The second roof marked M is a normal built-up roof and does not have a dropped ceiling.

By early morning, buildings that are constructed with dropped insulated ceilings and are adequately ventilated will have roof surface temperatures near ambient air temperature as indicated by roofs L and N in figure 5. Although roof M appeared warmer than roof L on the summer day thermal imagery, it appears colder than L on the summer night infrared imagery because of greater heat flow retardation from the interior of the roofs labeled M.

Most of the temperature variances shown in figure 9 were attributed to the presence of standing water on the roofs. Color and color infrared photography also verified these areas of standing water. However, the thermal image of Building 426 could not be explained by a study of either the aerial imagery or the building's roof construction drawings. The explanation came from the residents of Building 426. Each evening an attic fan was turned on and left running all night, and the attic door was left open. Consequently, the total effect of the warm air being drawn from the lower floors of this building into the attic, even though the attic floor was adequately insulated, created a heat loss that was detectable by thermal infrared imagery.

Figures 4 through 14. The second portion of this survey involved the acquisition of baseline environmental data. Major subjects investigated using aerial imagery were forestry, grounds, wildlife, and sanitary health problems. Data collected on the ground were utilized with aerial photography during the analysis procedure. The advantages of using winter or summer photography depends upon the type of environmental feature that is to be studied. Land drainage patterns, coniferous trees and shrubs, erosion, landfills, and unimproved grounds can be identified more readily on winter photography. Vegetation stress, recreation areas, sewage treatment plants, and water points are better analyzed using summer photography. The inventory of wildlife cover and deciduous vegetation is most easily accomplished by comparing these features on both summer and winter photography. Selected environmental features were identified and located on installation site marks as follows: sewage treatment plant; coniferous trees and shrubs; deciduous trees; garden plots; land drainage; grasslands; wildlife cover; and tall mowed grass.

The forests surrounding Vint Hill Farms Station are primarily an oak/hickory/Virginia pine association with an occasional stand of pure Virginia pine. These forests and surrounding grass areas provide excellent habitat for a wide variety of wildlife. The list of animals actually noted during the survey included, deer, rabbits, squirrels, racoon, opossum, fox, hawks, turkey vultures, woodpeckers, and a variety of song birds. The large grass areas provide ample habitat for rabbits, mice, and moles. Several varieties of fish can be found in South Run, which flows along the northwestern edge of the post.

From the standpoint of actual problems, the post was very clean. The photographic analysis located two dumping sites and a salvage area. These areas were noted for continuous monitoring because of an unexplained high trace mineral content discovered in the water quality survey.

Arlington Hall Station. The same type of analysis of the aerial imagery was also conducted for Arlington Hall Station as has been previously discussed for Vint Hill Farms Station.

The most significant feature detected on the Arlington Hall Station imagery during the survey was the apparent amount of thermal energy being lost from the station's underground steam lines. These lines were installed approximately 20 years ago and are used to supply heat to most of the buildings within the installation. The Facility Engineer was aware that the conditions of those lines had deteriorated, but the scheduled repair was held in abeyance until the results of this study were available. The winter night thermal infrared imagery indicated a number of sections along this system where repairs or replacements were needed.

Entrapped moisture was detected on a number of roofs at Arlington Hall Station from both the winter and summer night thermal infrared imagery. Due to large areas of standing water on these roofs during the winter phase of the study, the summer thermal imagery proved to be more useful. As with Vint Hill Farms Station, an initial report, an overlay of suspected heat loss areas, and other problem areas were supplied to Arlington Hall Station Facility Engineer within 1 week of the overflights.

ELECTRICAL SURVEY. The electrical distribution systems at Arlington Hall Station and Vint Hill Farms Station were inspected on 12 to 15 and 17 to 18 March 1976, respectively. Although Vint Hill Farms Station had no electrical problems, there were five faulty connections discovered at Arlington Hall Station that required maintenance. Also a number of connections at Arlington Hall were found that appeared to be faulty, but upon detailed inspection proved to be the result of circuit imbalance. Figures 10 and 11 are presented to illustrate the ability of the infrared equipment to locate maintenance areas in a highly effective and safe manner. Figure 10 shows an electrical distribution pole containing high-voltage circuits. Figure 11 is a reproduction of the infrared display that indicates a faulty connection either at the cable termination or at the lightning arrester on the same pole.

ROOF SURVEY. The aerial thermal infrared imagery and aerial photographs of the two stations were analyzed in an attempt to identify those roofs that indicated a need for repair, i.e., showed indications of deterioration. During this analysis and review of the installation's engineer drawings, it was learned that only a few buildings at Vint Hill Farms Station had flat, built-up, insulated roofs. Time limitation precluded a complete onsite roof survey at either station; therefore, a building (No. 162) was selected at Vint Hill Farms Station for a detailed ground visual and thermal infrared survey.

The roof of Building 162, a barracks, had two areas that were indicated by the handheld infrared equipment to be underlain by wet insulations. The first area was associated with a guyed television antenna that was installed improperly, enabling precipitation to penetrate the moisture barrier (figures 12 and 13). The second area detected was near the roof parapet and was probably caused by an open joint in the flashing.

WATER QUALITY.

Winter Phase. With the exception of cadmium and mercury, the survey indicated normal concentrations of the other parameters. In view of the limited amount of sampling conducted and the fact that the mercury and cadmium concentrations were higher than expected but not at a dangerous level, these parameters were resampled during the summer phase.

Summer Phase. The analysis indicates that the total phosphate concentrations recorded at the sample points were greatly above the standards set for streams and water bodies. Total phosphate concentrations in a stream should not exceed 50 µg/l (micrograms per liter) at the point where it enters any body of water.* Although there are a number of mitigating factors involved in the determinations of the exact effects of phosphates on lakes and streams, these high values can cause an acceleration in eutrophication. All other parameters including cadmium and mercury were found to be at normal levels.

*U.S. Environmental Protection Agency, Quality Criteria for Water, 1976, Pre-Publication Copy.

DISCUSSION

At the installation level, the U.S. Army Facility Engineer is currently facing our country's increased emphasis on energy conservation and environmental protection programs with reduced resources and without the use of available technology. To develop an effective solution to this problem, a Government interagency team was formed to demonstrate the capabilities of remote sensing technology for detecting energy losses and controlling environmental pollutants. Major areas of study included in this demonstration were electrical distribution systems, structures, steam lines, grounds, forestry, fish, wildlife, and sanitary/health.

The technical approach utilized three types of aerial photography, ground surveys, and two USASA installations to examine the feasibility and to determine the requirements of an environmental and energy assessment of Army installations.

AERIAL IMAGERY. Successfully using remote sensing technology for environmental and energy loss surveys depends on the type, scale, and quality of imagery, weather conditions, type of collateral material available, and the knowledge of the image interpreter of the subject under analysis. Of these factors, the two considered most important are the availability of collateral information (construction drawings, etc.) and the interpreter's knowledge of the installation (which buildings are heated, locations and type of roof repair, etc.). As with any new technology, formal training in image interpretation would be beneficial, but during the course of this program, it was discovered that many of the patterns detected on the various types of imagery could readily be explained by the Facility Engineer staff of the two installations. In most cases, these questions were answered by reference to as-built engineering drawings, but many times the answer relied on the Facility Engineers' personal knowledge of their installations' maintenance and repair work.

The thermal imagery for this study was acquired between the hours of 0200 to 0500 and again at midday during the summer and winter seasons at scales of 1:2,000 and 1:4,000. Based on a review of the literature and the results of this study, it is now believed that the period of greatest thermal contrast between wet and dry areas of insulation occurs 2 to 3 hours after sundown, rather than during the predawn period. The major source of thermal energy that creates this thermal contrast is the sun and not internal heat from the buildings. In analyzing the effectiveness of day/night, winter/summer flight times, and the scale of the thermal infrared imagery, there are a number of factors to be considered. They include geographic location of the installation, size or area, and the location of the buildings within the installation. Obviously for locating thermal energy losses through the roofs of buildings, i.e., sky lights, roof vents, lack of insulation, the most effective time of acquiring the imagery would be at night and in the winter when the buildings are heated. As demonstrated in this study, thermal imagery acquired during the daytime is not effective for detecting either heat losses or wet insulation. Although the 1:2,000 scale imagery provided the interpreter with a more detailed picture to analyze, a scale of 1:4,000 would be more advantageous for three reasons. First, all heat loss areas detected on the 1:2,000 scale imagery could also be resolved on the 1:4,000 scale. Second, and most important, correlation between the three types of imagery is more efficient and manageable with the 1:4,000 scale because of the increased ground area covered. Third, the reduction in the amount of imagery obtained during succeeding years permits a more efficient design of image use, storage, and retrieval.

Weather conditions and the amount of standing water on the roofs are also important considerations when selecting the time of image acquisition. To obtain the maximum thermal differences on the ground, the sky should have less than a 10 percent cloud cover with a 0 to 4 miles per hour (0 to 6.4 km per hour) wind speed. Standing water on the roofs of buildings during the time of image acquisition can conceal areas of wet insulation and create false indications of energy loss. When possible, image acquisition should be delayed until all roofs are free of standing water.

The physical properties of roof surfaces, such as repaired or patched areas, variances in gravel color and density, and surface moisture can produce different tonal patterns on the thermal imagery, even though their surface temperature are uniform. If not properly identified, these patterns could be misconstrued as either areas of heat loss or wet insulation. Examination of the aerial photography and the as-built installation engineering drawings should provide the Facility Engineer with the essential information for the correct identification of each different tonal pattern on the thermal imagery.

The aerial photography, color and color infrared, was acquired simultaneously during the winter and summer phases of this study at a scale of 1:2,000. Although one film type may have been adequate, the additional information provided by the visible and near infrared regions of the spectrum in comparison with the small additional cost of acquisition was believed to be justified. Ideally, this photography should be obtained between the hours of 1000 and 1500 at a scale of 1:20,000 for environmental analysis and 1:10,000 for identification of the physical features or building roofs. The 1:2,000 scale photography proved to be almost unmanageable because of the excessive amount of photos acquired at this scale.

ELECTRICAL SURVEY. Using handheld infrared imaging devices, such as the PAS-10, will provide the Facility Engineer with an expedient, cost-effective means for determining the condition of an installation's electrical distribution system without interruption of power service. In many instances, an annual survey with this equipment could certainly reduce, if not eliminate, the chances of both unscheduled power and equipment failure by locating potential trouble areas in advance. In investigating the time involved in an infrared survey to that of the existing methods, it was discovered that a scheduled preventative maintenance procedure for electrical distribution systems did not exist for most installation. If such a procedure did exist, however, it would require approximately 10 to 20 times the number of manhours than a similar infrared inspection and, of course, would create numerous interruptions of service.

ROOF SURVEY. In addition to the electrical power, the PAS-10 can also be employed by the Facility Engineer to detect entrapped moisture within the insulation of flat, built-up roofs. Using this ground survey method in conjunction with aerial imagery can provide the Facility Engineer with a simple, efficient, cost-effective method of surveying the roof maintenance requirements of an entire installation in a very short period of time. By using aerial photography, the Facility Engineer can determine the physical appearance of any type of roof and determine, for example, the need for replacement of missing shingles or for replacement of a roof. Aerial thermal infrared imagery is employed to detect those areas of flat, built-up roofs that are probably underlain with insulation. Once the approximate location of a roof's moisture barrier defect has been determined from aerial imagery, an onsite roof survey can be conducted with the handheld infrared equipment to determine the exact location of the entrapped moisture.

A roof survey conducted by this method will not detect all the areas where maintenance is required; however, it will locate those areas that are in need of major repair.

In summary, remote sensing technology is not a panacea that can be used to detect all of the energy and environmental problems that can exist on an installation, nor can it presently provide quantitative information; however, it does provide the Facility Engineer with a valuable tool that can be used to detect problem areas that may have been overlooked during the ground inspection.

CONCLUSIONS

1. Aerial infrared imagery taken at scales of 1:4,000 and used in conjunction with a handheld infrared imaging device provides a cost-effective method for detecting and determining the area entrapped with moisture in flat, built-up roofs.
2. Aerial photography at scales of 1:10,000 used in conjunction with thermal infrared imagery and collateral information provide the Facility Engineer with an efficient, cost-effective method for detecting and characterizing thermal losses through the roof of buildings and associated utilities, such as steam lines.
3. Color and color infrared aerial photography obtained at scales of 1:20,000 can provide the Facility Engineer with a capability for establishing a baseline of environmental conditions and a method for monitoring potential environmental problem areas.
4. The handheld infrared imaging device provides an efficient, cost-effective method for surveying the maintenance requirements of an installation's electrical distribution system without disruption of service.

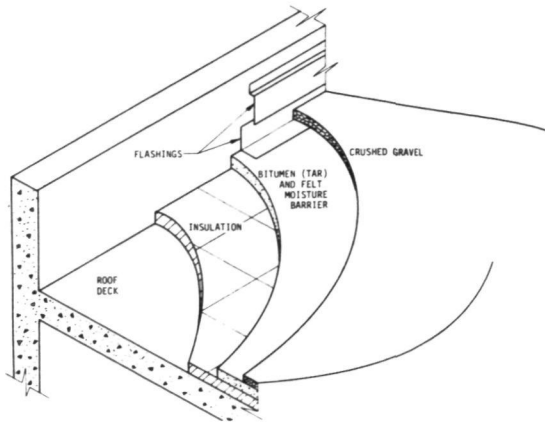


FIGURE 1.
CONSTRUCTION OF A BUILT-UP FLAT ROOF



FIGURE 2.
PAS-10 THERMAL INFRARED DEVICE

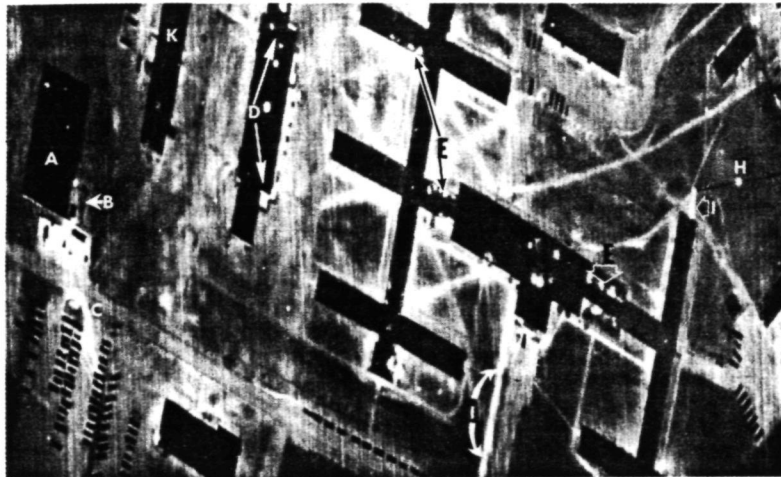


FIGURE 3.
AERIAL THERMAL INFRARED IMAGERY TAKEN AT 0420 HOURS ON 18 MARCH 1976

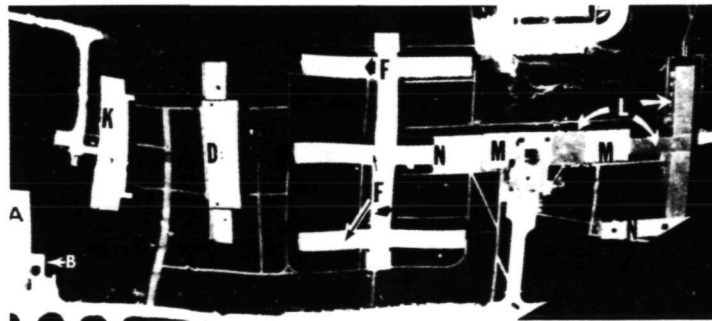


FIGURE 4.
AERIAL THERMAL INFRARED IMAGERY TAKEN AT 1530 HOURS ON 20 JULY 1976

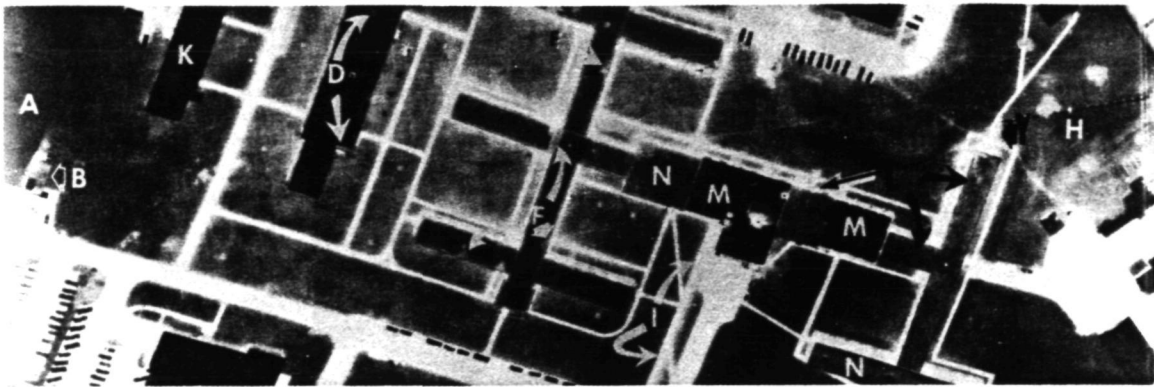


FIGURE 5.
AERIAL THERMAL INFRARED IMAGERY TAKEN AT 0450 HOURS ON 21 JULY 1976

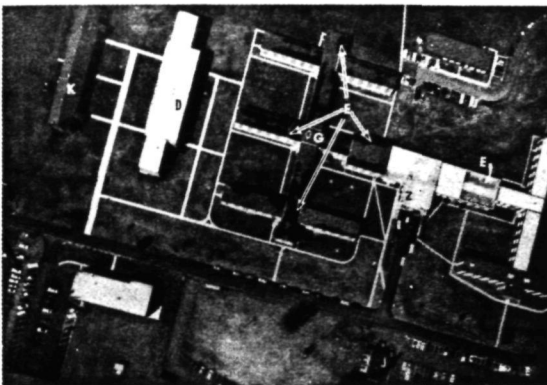


FIGURE 6. AERIAL COLOR PHOTOGRAPHY TAKEN
AT 1345 HOURS ON 18 MARCH 1976. SCALE -
1:2,000

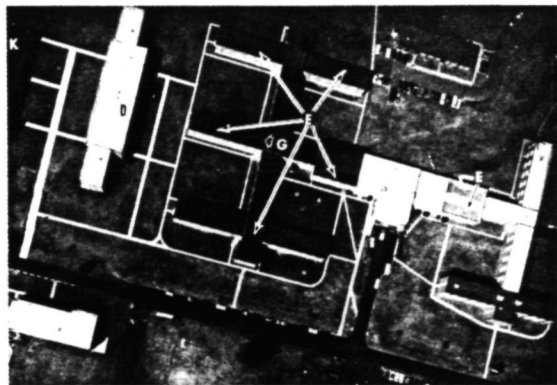


FIGURE 7. AERIAL COLOR INFRARED TAKEN AT
1345 HOURS ON 18 MARCH 1976. SCALE -
1:2,000

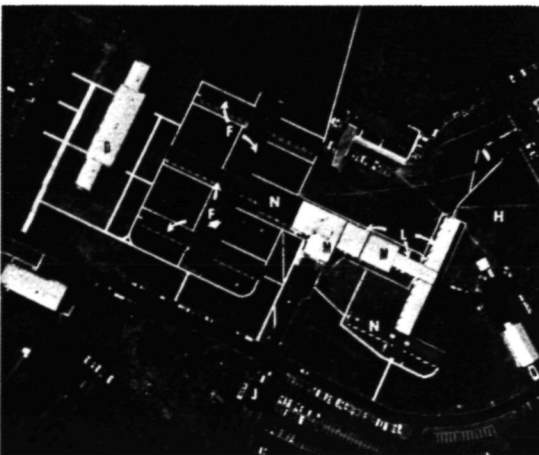


FIGURE 8. AERIAL COLOR INFRARED PHOTOGRAPHY
TAKEN AT 1530 HOURS ON 20 JULY 1976. SCALE -
1:2,000

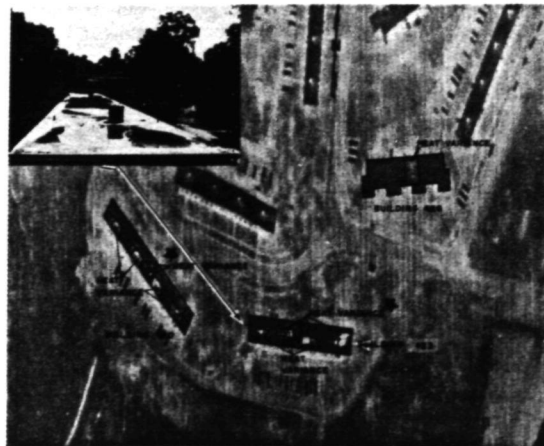


FIGURE 9. AERIAL THERMAL INFRARED IMAGERY
TAKEN AT 0430 HOURS ON 18 MARCH 1976

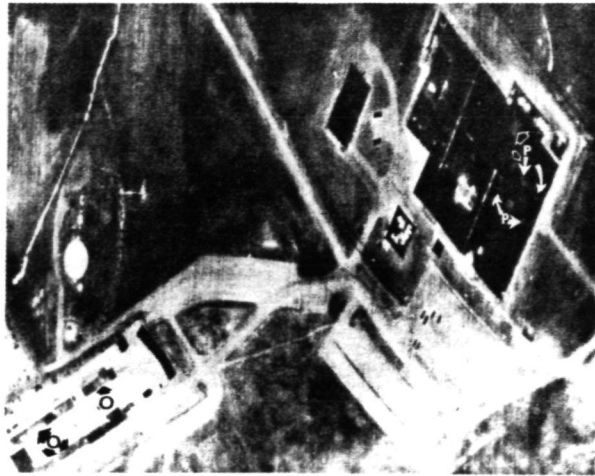


FIGURE 10.
AERIAL THERMAL INFRARED IMAGERY TAKEN AT 0430 HOURS ON 18 MARCH 1976

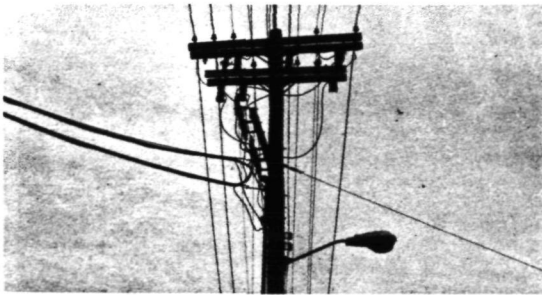


FIGURE 11. AN ELECTRICAL DISTRIBUTION POLE
CONTAINING HIGH VOLTAGE CIRCUITS

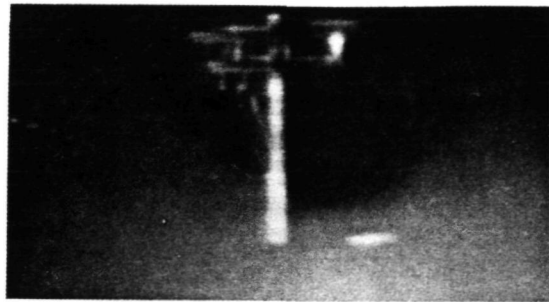


FIGURE 12. A REPRODUCTION OF THE INFRARED
DISPLAY INDICATING A FAULTY CONNECTION



FIGURE 13. AN ANTENNA INSTALLATION OF
BUILDING 162, VINT HILL FARMS STATION.
AREA OUTLINED IS UNDERLAIN BY WET
INSULATION.



FIGURE 14. INFRARED DISPLAY OF WET INSULATION
AREA ON BUILDING 162 CAUSED BY FAULTY
INSTALLATION OF TELEVISION ANTENNA

THE OPERATIONAL PROCESSING OF WINDESTIMATES FROM CLOUD MOTIONS:PAST, PRESENT AND FUTURE

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ABSTRACT

The development of operational procedures for the extraction of wind estimates from cloud motions observed in geostationary satellite data has been an evolutionary process. In 1969, the first operation was instituted at NESS using visible pictures from the ATS-1 and ATS-3 satellites. Operational procedures consisted of the viewing of an animated film loop by a meteorologist who determined the beginning and end points of the cloud displacements. The conversion of displacement end points to earth located high and low level wind estimates was crude, cumbersome and subjective. These procedures provided approximately 300 wind estimates per day to a very small user community.

Current NESS Winds operations provide approximately 1800 high quality wind estimates per day to about twenty domestic and foreign users. This marked improvement in NESS Winds operations was the result of computer techniques development which began in 1969 to streamline and improve operational procedures. In addition, the launch of the SMS-1 satellite in 1974, the first in the second generation of geostationary spacecraft, provided an improved source of visible and infrared scanner data for the extraction of wind estimates. Currently, operational Winds processing at NESS is accomplished by the automated and manual analyses of infrared data from two geostationary spacecraft. This system uses data from SMS-2 and GOES-1 to produce wind estimates valid for 00Z, 12Z and 18Z synoptic times.

As for the future, development of automated winds processing techniques will focus on the extraction of high- and low-level wind derivations with temperature/height estimates and the use of objective procedures for the quality control of the wind estimates. Development of manual techniques will focus on the implementation of a Man/Machine Interactive Processing System (MMIPS) approach to satellite wind extraction. The MMIPS will provide the use of digital data for time-lapse animation and permit greater interaction between the meteorologist and the main computer complex for winds derivation and quality control. An outlook of the processing capabilities for the First GARP Global Experiment (FGGE) is provided.

1. INTRODUCTION

With the launch of the first geostationary satellite, ATS-1 in 1967, meteorologists began to analyze the first full disk images of the earth and its cloud patterns. It occurred to some meteorologists that if time lapse film loops could be made, the dynamic aspects of these cloud patterns could be

studied and related to various weather phenomena. Pioneers in the field of cloud motion analysis and its relationship to wind fields included Dr. Verner Suomi of the University of Wisconsin and Dr. Tetsuya Fujita of the University of Chicago. They concluded that two levels of cloud motion, cumulus level and cirrus level, could be easily analyzed and they began to develop techniques for relating these motions to the low and high level wind fields. The results of their experiments were evaluated by Hubert and Whitney (1971). They compared the derived cloud motion vectors with co-located rawinsonde reports and determined that low level cumulus clouds best matched rawinsonde reports at 914 meters and high level cirrus clouds fit best at 9114 meters. Median vector deviations of cloud motions from rawinsonde reports at those levels were 5 mps and 9 mps respectively. These tests indicated a high correlation between cloud motion analysis and rawinsonde derived wind data.

2. YESTERDAY'S OPERATIONAL SYSTEM

In order to track cloud motion tracers, meteorologists prepared latitude-longitude gridded, time lapse film loops of approximately 2½ hours duration and projected the animated cloud motion sequence on a paper worksheet. Meteorologists then selected those cloud tracers which seemed to be moving with the high and low wind fields and marked their start and end points on the worksheet. In order to measure the wind speed, the analyst placed a clear plastic template, calibrated to the lat-lon grid, over the end points and determined a preliminary speed value. In order to rectify the flat plane film projection to the earth's spherical coordinate system the meteorologist had to add a speed correction as a function of each vector's distance from the satellite subpoint. Similarly, the meteorologist used a clear plastic compass and manual corrections to estimate direction of motion.

Since the Applications Technology Satellites carried only visible sensors, operations were limited to the daylight hours. The north and south Atlantic Oceans were analyzed at 1800GMT and the Pacific areas at 0000GMT. During the period 1969 through most of 1971, the combination of cumbersome manual techniques and daylight analysis limited the production of satellite derived winds to approximately 300 per day.

These data were used in the tropical analysis model at the National Meteorological Center. The model's developer, Dr. Harold Bedient, found that satellite derived winds were useful for providing reliable and meteorologically sound data over tropical oceans and other data void areas.

3. OPERATIONAL IMPROVEMENTS IN THE 1970'S

3.1 COMPUTER TECHNOLOGY

The implementation of computer techniques in the operation served to free the meteorologist from the drudgery of routine analysis and hand calculation and permitted him to concentrate on the analysis of complex meteorological phenomena. In October 1971, computer techniques were implemented at NESS which provided for the automation of the hand calculations necessary to transform vector end point data to earth located wind estimates (Young et. al. 1972). Techniques development conducted by Bristor et. al. (1967) and Leese et. al. (1970) demonstrated the feasibility of measuring cloud motion displacements by computer methods. This work laid the foundation for the development and operational implementation of an automated procedure providing for the derivation of low level wind estimates (Bradford et. al. 1972).

3.2 ADVANCES IN SATELLITE TECHNOLOGY

The launch in August 1974 of the first in a series of Geostationary Operational Environmental Satellites (GOES) provided infrared data for the derivation of wind estimates. This improved source of data permitted the analysis of night time cloud motion displacements. In addition, the infrared data enabled the meteorologist to provide quantitative height assignments to the wind estimates through the translation of cloud temperatures into pressure altitude values.

4. TODAY'S SYSTEM FOR WINDS' PROCESSING

Low level wind estimates are provided by automated procedures using the IBM 360/195 computer system. High level wind estimates are produced by manual procedures augmented by mini-computer capabilities and the IBM 360/195 computer. In addition, manual procedures provide the final quality control of the high and low level wind fields. Wind estimates are derived for 00Z, 12Z and 18Z synoptic times using infrared data (4x8 km resolution) from the SMS-2 and GOES-1 satellites with geographical coverage from 177.5°E to 25.0°W longitude and 45°N to 45°S latitude. A generalized flow diagram of the Winds' Processing System is shown in figure 1.

4.1 AUTOMATED PROCEDURES

There are three basic components comprising the automated operation - Pre-Processing, Picture Pair Processing and Winds Editing.

4.1.1 PRE-PROCESSING. For each operation (00Z, 12Z and 18Z), a sequence of four pictures (30 minutes apart) are ingested from both GOES-1 and SMS-2 and acquired on magnetic tape. Although only two pictures per spacecraft are used for Winds' processing, four pictures are acquired to provide backup pictures in the event one or both of the pictures normally used are of poor quality. Each picture is pre-processed on the IBM 360/195 immediately after ingest. The pre-processing function provides for the quality control of the data (detection of format anomalies, scan line dropout, etc.), the transfer of data from magnetic tape to disk, and the computation of earth centering coordinates required for earth location.

4.1.2 PICTURE PAIR PROCESSING. This segment of the processing is comprised of three vital components - Data Evaluation, Landmark Registration and Cloud Target Selection and Measurement.

4.1.1.1 DATA EVALUATION. With the completion of the pre-processing, a four picture data base resides on disk for each satellite providing five possible picture pair candidates (having time intervals of 30 or 60 minutes) for processing. Diagnostic information from the pre-processing segment is used to evaluate the data quality of each picture. Consideration is given to the rapid life cycle (growth and decay) of clouds with greater weight given to picture pairs having 30 minute intervals. Also, greater weight is given to the pair nearest the synoptic analysis time (00Z, 12Z and 18Z). A merit score for each pair is determined considering the above factors and the pair with the highest merit score is selected for processing.

4.1.1.2 LANDMARK REGISTRATION. Precise registration of the two picture images is required to measure cloud motions accurately. Investigation has shown that the misregistration of earth located landmarks common to both pictures is a result of a translation error and therefore constant. The Landmark Registration procedure applies cross correlation to landmarks common to both pictures to determine the correction necessary to align the two pictures (Green et. al. 1975). A 32x16 array, centered on a predefined landmark latitude longitude point, is extracted from picture "A"; and a companion 64x32 array, centered on the same point, is extracted from picture "B". Cross correlations are computed for all possible positions of the smaller array within the larger array. These positions are identified by their vertical and horizontal lag values; which range from -8 to +8 in the vertical and -16 to +16 in the horizontal. The displacement of the maximum correlation, relative to the center of the 33x17 array of correlations, is the displacement of the target. This procedure is applied to as many as eighty landmarks and the target displacements are stored in the computer. Since cloud-free landmarks have the same displacement, the stored values are examined for consistency and the registration correction is determined. Cloud covered landmarks display spurious displacements resulting from the motion of the clouds over the 30 or 60 minute time interval.

4.1.1.3 CLOUD TARGET SELECTION AND MEASUREMENT. Potential low level targets are defined at pre-selected 2½ latitude longitude locations. A 32x16 array centered on a pre-selected latitude longitude location is extracted from Picture "A" and examined with regards to being a potential low level cloud target. The low level temperature range used in this examination is determined

(for each latitude longitude location) from conventional 700 mb and 1000 mb temperature analyses. If 30% or more of the array values fall within the low level temperature range, the target is accepted as being valid for displacement measurement. If the array examined does not meet this requirement, it is rejected from consideration and the next potential target is extracted and examined.

Once the target has passed the selection criteria, a 64x32 array centered on the same latitude longitude location is extracted from Picture "B" (the later picture). The cloud motion displacement is determined using a refinement of the basic cross correlation algorithm, called temperature slicing, which is applied to the 32x16 target array and companion 64x32 search area array. In this approach, the temperatures contributing to the coefficients obtained from the correlation of the target area and companion search area are only those which fall within the low level temperature range. This is accomplished by nullifying the contribution made by the temperatures which exceed the range.

In the normal situation, the determination of the cloud motion displacement would require the computation of $33 \times 17 = 561$ correlation coefficients. To minimize the number of computations required, the First Guess/Fast Displacement Algorithm was developed. This technique uses a first guess (850 mb wind from the latest analysis) and pre-defined allowable deviation from the first guess to define an optimal search A in the cross correlation matrix. Coefficients are computed for area A' which is slightly larger than the optimal search area A. The areas A' and A may be thought of as two concentric rectangles. If the maximum coefficient is found in area A, it is assumed to be the maximum coefficient of the entire cross correlation matrix. However, if the maximum (value) is not found in A, coefficients are computed for all of the 561 lag value positions which are then scanned for the maximum (value). At the completion of this process, the cloud motion displacement obtained from the correlation matrix is translated into an earth located wind estimate (expressed in meteorological notation).

The computation of image coordinates (scan line and sample), given a latitude longitude, is accomplished by a variation of the approach used in the image mapping and gridding of GOES data (Ellickson, 1975 and Shellman and Dolittle, 1975).

4.1.3 WINDS EDITING. At this stage, the computation of the low level wind field has been completed and the automated editing procedures are applied. First, obvious erroneous wind estimates are removed when the absolute speed difference between the wind estimate in question and the 850 mb wind exceeds 15 mps. Second, the remaining wind estimates undergo three independent quality tests based upon the analysis of cross correlation parameters and the deviation of the wind estimates in question with the 850 mb analysis and adjacent neighbor wind estimates. Depending upon the results of the tests, each wind estimate is assigned a Quality Index (QI) or rejected. The QI is defined as the percent probability that a meteorologist would accept the given wind estimate as being meteorologically sound. At the end of this process, the quality controlled wind estimates are stored in the IBM 360/195 computer and a facsimile mercator map containing the wind field is prepared and presented to the meteorologist for his evaluation.

4.2 MANUAL PROCEDURES

The components of the winds system providing for the manual procedures are - Loop Movie Generation, Target Selection and Measurement, Target Temperature Determination and Wind Computation (Young, 1975).

4.2.1 LOOP MOVIE GENERATION. Infrared picture data of 8 km resolution are acquired on film recorder. After photographic processing, the pictures are manually registered and a loop movie is made consisting of five picture images taken over a 2 hour time span.

4.2.2 TARGET SELECTION AND MEASUREMENT. An overhead movie projector is used to display the film loop on a paper worksheet placed on a plotting board. The meteorologist studies the projected animation and selects the appropriate high level targets. The analyst measures cloud displacement by pencil marking the initial and final position of the cloud target with the direction of flow

indicated by an arrow. After the target displacement measurements have been obtained, the analyst derives the temperature for each target.

4.2.3 TARGET TEMPERATURE DETERMINATION. The analyst is assisted in his determination of cloud target temperature through the use of the Man-Machine Interactive Processing System (MMIPS) (Bradford et. al. 1975). The MMIPS enables the analyst to display the satellite observed cloud target temperature in gray scale and numerical format. In addition, the MMIPS computes and displays a standard frequency distribution for a 17x17 array of cloud target temperatures and provides corrected cloud target temperatures based upon different emissivity values. The corrected cloud target temperature is determined using the digital infrared data corresponding to the middle picture of the film loop. Once the data have been loaded into the MMIPS, the analyst can display the target used for the displacement measurement. From the frequency distribution, the analyst determines the temperature of the coldest cluster of satellite observed target values (B_T). From the loop movies, the analyst estimates the emissivity (E), defined as the radiating efficiency of a blackbody. For $E=1$, B_T is accepted as the target temperature. For $E=0.75$, 0.85 and 0.95 , a corrected target temperature (B_C) is computed using the following equation: $B_C = (B_T - B_S(1-E))/E$ where B_S is the satellite observed background temperature. For $E < 0.75$, the meteorologist will omit the cloud target from consideration or assign the cloud motion vector to a pressure level he determines as appropriate based upon his knowledge of the synoptic situation. Target temperatures are recorded on the worksheet with their corresponding vector end points.

4.2.4 WIND COMPUTATION. The translation of the vector end points into wind estimates and the translation of the MMIPS derived temperatures into specific pressure altitudes are accomplished by computer procedures. The vector end point information and the corresponding temperatures on the worksheet are recorded on punch cards through the use of a "Datagrid Digitizer" which is connected to a card punch. The vector end point information on punch cards is then submitted to the IBM 360/195 for processing.

The computer processing involves the translation of the vector end point information in digitized x,y coordinate format to earth located cloud motion vectors. Once the vector has been earth located, the MMIPS derived temperature is referenced to the latest analyzed vertical temperature profile (provided by the National Meteorological Center) at that location to determine the pressure altitude.

4.3 FINAL QUALITY CONTROL/MANUAL EDITING

Manual analysis techniques provide the final quality control of the wind estimates produced by the automated and manual procedures. The facsimile display containing the low level wind estimates is carefully inspected by the meteorologist. He transcribes the latest surface pressure field, frontal systems and high level cloud pattern to the facsimile display. In complex situations, he may refer to the loop movie. To be acceptable, each low level vector must be in approximate agreement with the geostrophic flow derived from the previous six hourly surface chart and the two hour loop movie. Since each low level estimate has a unique identifier, the rejected estimates are readily purged from the computer disk file. The high level wind estimates are quality controlled in a similar manner using the latest 500 mb and 300 mb analysis. The edited wind estimates are then moved to the disk product file where they can be accessed by the National Meteorological Center for use as input to all Analysis and Production Models. The product vectors are also reformatted by computer into an observation code form for teletype transmission to world-wide users. High and low wind estimates from a typical operation are shown in figure 2.

4.4 SUMMARY - TODAY'S SYSTEM

Currently, NESS provides approximately 600 Wind estimates per analysis cycle or 1800 per day compared to approximately 300 per day for the yesterday's winds' processing system. The user community receiving these data has expanded from a very limited number of domestic users in the late 1960's and early 1970's to well over twenty domestic as well as foreign users at the present time.

Prior to August 1974, when winds analysts used only visible imagery for cirrus level cloud motion analysis, all tracers were arbitrarily assigned to the 300 mb level in the extratropics and the 200 mb level in the tropics. Vector deviations of these high level wind estimates from co-located rawinsonde winds are depicted by the solid line on figure 3. Since the advent of IR SMS/GOES imagery and the subsequent use of the MMIPS derived temperature and pressure altitude values, these deviations from rawinsonde reports (at the assigned level) have been reduced significantly. The position of the dashed line in figure 3, indicates approximately 10% reduction in the magnitude of these deviations.

5. TOMORROW'S (1978-1980) PROCESSING SYSTEM

Figure 4 portrays the evolution of the processing system for winds that is planned for operation in 1978.

5.1 DIRECT INGEST SYSTEM AND GOES DATA BASE: (1) IN FIGURE 4

A hardware/software system that will acquire data from the satellites and then transmit data directly to the IBM 3330 disk drives for direct access via the IBM 360/195 system is currently under development. This "Direct INGEST SYSTEM" will eliminate today's manual tape handling system. Once the raw VISSR data are available to the IBM 360/195, a software system will extract "sectors" of the data, which represent about 100-degrees longitude by 100-degrees latitude centered at the subpoint of each satellite. These sectors will be preprocessed into a "GOES Data Base" that is time oriented, earth located, calibrated and formatted for multiple applications. This step replaces the preprocessing now done for the P/P software and further replaces the photographic process needed to prepare the movie loop for projection onto the digital data grid. It is anticipated that a full 24 hours of 8-km resolution, infrared sectors from each satellite can be stored in the data base.

5.2 WINDS' INTERACTIVE PROCESSING SYSTEM (WIP): (2) in FIGURE 4

This hardware and software system uses the analysis functions of the MMIPS to replace the photographic movie loops, the digitizer board (data grid), and the card-punch system of entering vector-end point and temperature data into the IBM 360/195 system. An analyst at the MMIPS console can call for a sequence of images from the GOES data base, display those images in the cine-motion on a high-resolution TV screen, and designate the beginning and ending points of cloud tracers, and calculate temperature-height relationships (DOSS). This interactive system automatically supplies cloud-tracer-end-point data to the vector calculation program (LUPWND II) ("4" in figure 4) in the IBM 360/195. A paging and recording system on a cathode ray tube (CRT) display allows the analyst to review his work prior to submitting the data to the large computer. This CRT system with its keyboard provides the interactive functions for the analyst.

5.3 VECTOR EDITING (VET): (3) IN FIGURE 4

The manual procedures of plotting cloud motion vectors on conventional weather maps, punching deletions on cards, comparing different images to various map projections by eye, etc., are to be replaced by the interactive system called VET. Data and analysis fields from the NMC's data sets that are resident on the IBM 360/195 computer are accessed and presented to the analyst on the TV screen of the MMIPS station. The outputs of both LUPWND II (the manually derived vectors from WIP) and P/P (the automated low-level vector system) can be superimposed and mixed with image data and analysis fields under analyst control. Various graphical and color-display modes are possible along with a variety of map scales, sector enlargements, and map projections that are selectable by the analyst. Vector values can be corrected and keyed directly into the IBM 360/195 system without going through the punched card system currently in use. It has been estimated that this interactive editing system, compared to the current processing system, will save approximately one hour of processing time.

6. A SCENARIO OF OPERATIONS IN 1978

6.1 TODAY'S OPERATIONAL SCHEDULE

Figure 5a (Today's System) depicts today's processing system as a function of time for the 1200Z synoptic analysis cycle. This procedure is duplicated for the 0000Z and 1800Z analysis cycles. The left column depicts the sequence of automated events. The center column shows the only current operational application of the MMIPS for winds' processing. The right column presents the manual movie-loop system. "LFM model" refers to the limited fine mesh model of the NMC, which provides basic forecast guidance for the continental United States. "PE model" refers to the analysis cycle of the NMC global primitive equation prediction model.

6.2 TOMORROW'S OPERATIONAL SCHEDULE

Figure 5b (Tomorrow's System) is a possible schedule for the implementation of the processing capabilities described in this paper. Note that much of the manual portions of the processing are to be done via the MMIPS. There are no film movie loops, and there is to be a close interaction between the analyst and the large computer system. Being relieved from many tedious, manual chores the meteorologist/analyst will be able to devote more attention to the careful selection of cloud-motion targets, the careful tracking of the targets, and the quality control of his work. The automation of process and calculations leads to increased efficiency, faster delivery of data, and greater reliability of production. This system will provide the capabilities to produce a large quantity of high-quality wind data for the FGGE data sets.

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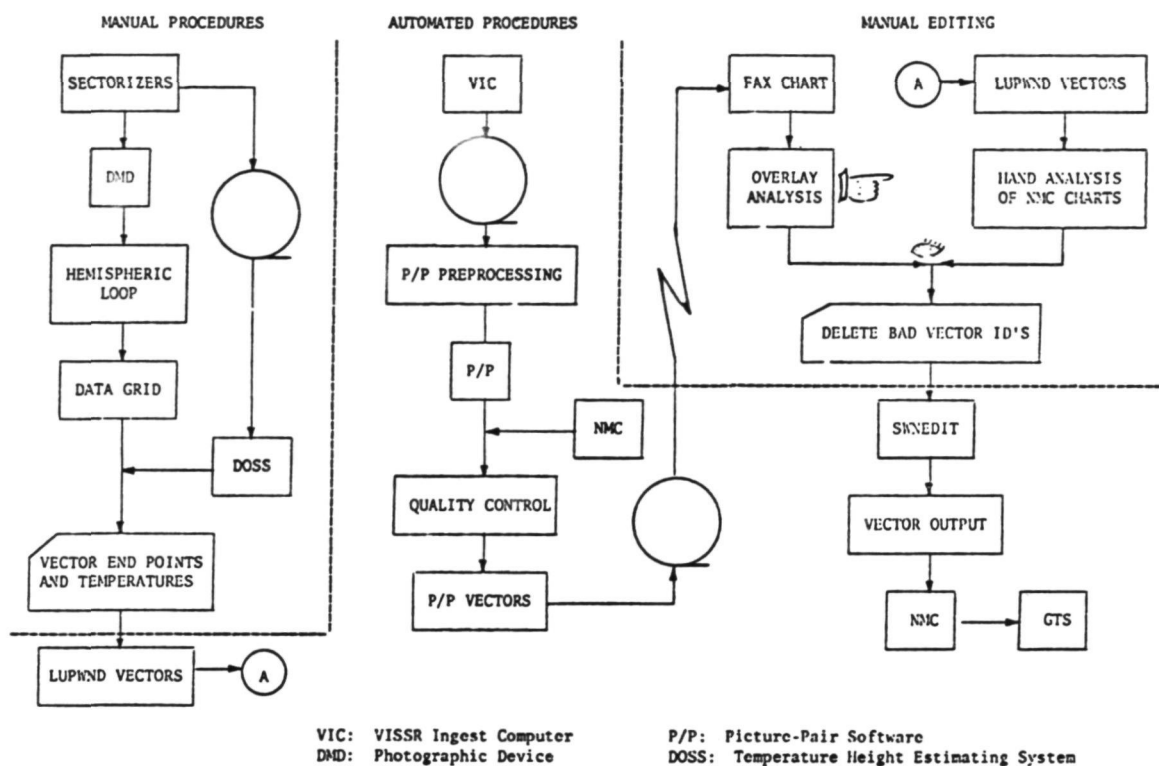


FIGURE 1. TODAY'S PROCESSING SYSTEM

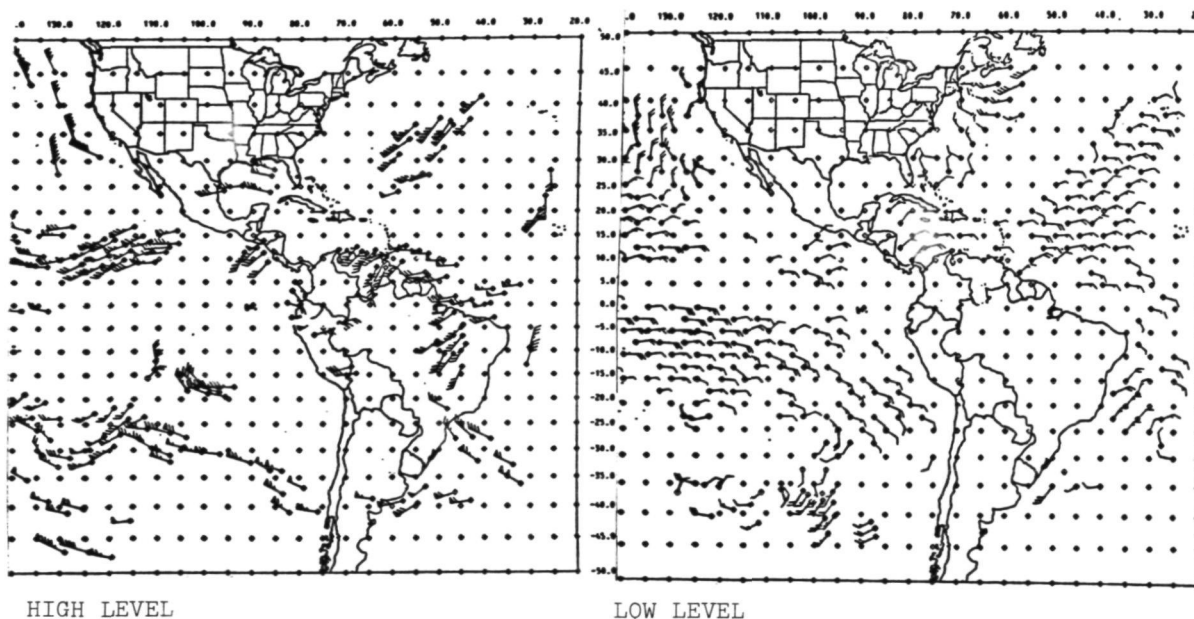


FIGURE 2. HIGH AND LOW LEVEL WIND ESTIMATES, 1000Z, APRIL 13, 1976

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SATELLITE DERIVED WIND VECTORS AS COMPARED TO RAWINSONDE DATA

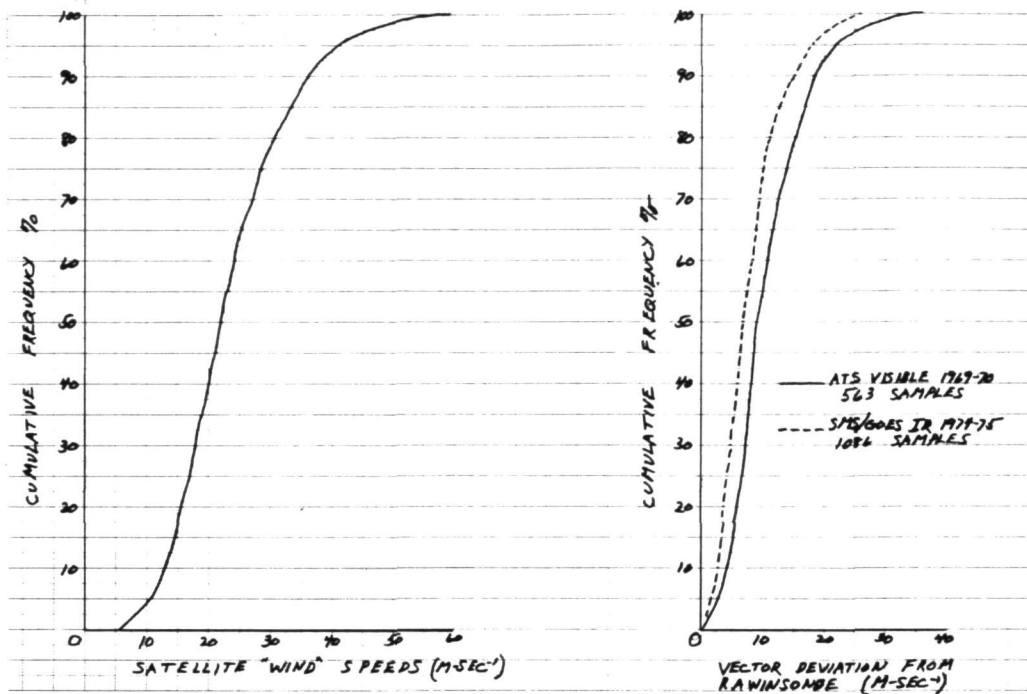


FIGURE 3. VERIFICATION COMPARISONS

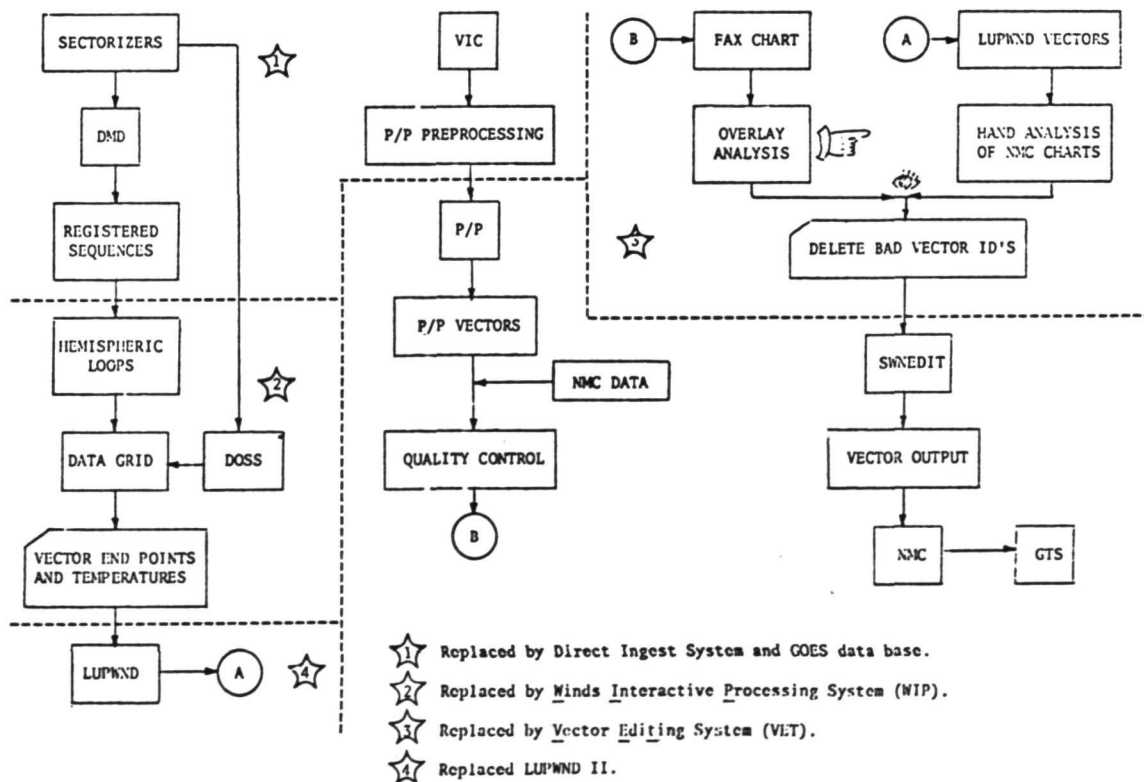


FIGURE 4. EVOLUTION OF TOMORROW'S PROCESSING SYSTEM

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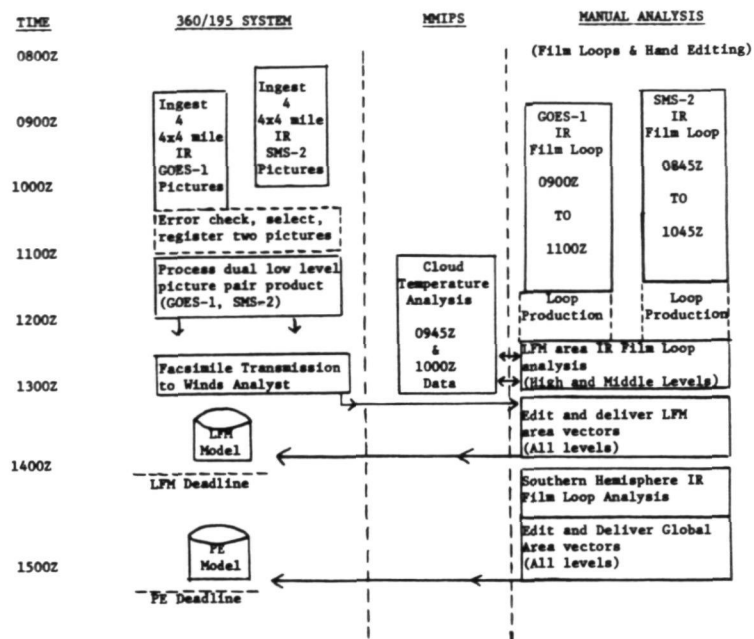


FIGURE 5a. TIME FLOW - TODAY'S SYSTEM

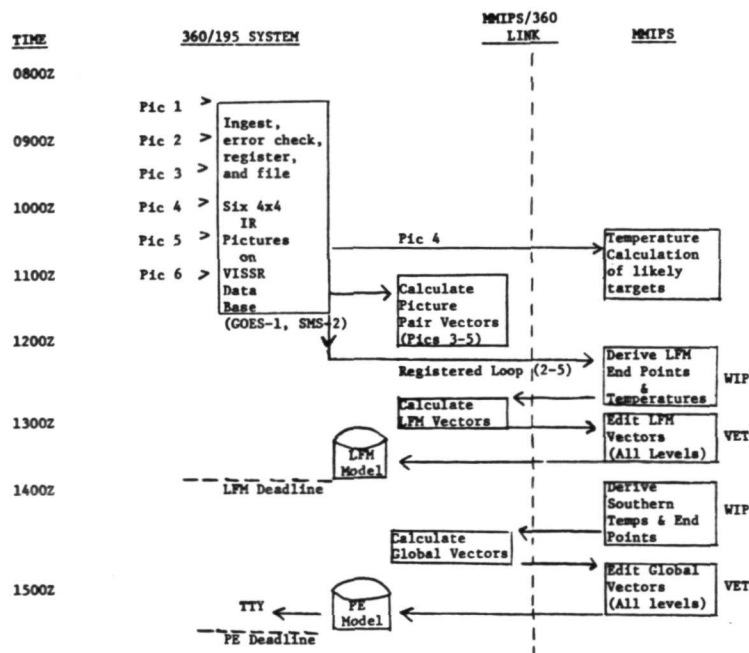


FIGURE 5b. TIME FLOW - TOMORROW'S SYSTEM

DATA PROCESSING FOR THE
DMSP MICROWAVE RADIOMETER SYSTEM

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ABSTRACT

A software program has been developed and tested to process microwave radiometry data to be acquired by the microwave sensor (SSM/T) on the Defense Meteorological Satellite Program (DMSP) spacecraft. The SSM/T 7-channel microwave radiometer and systems data will be data-linked to Air Force Global Weather Central (AFGWC) where they will be merged with ephemeris data prior to product processing for use in the AFGWC Upper Air Data Base (UADB). The overall system utilizes an integrated design to provide atmospheric temperature soundings for global applications. The fully automated processing at AFGWC is accomplished by four related computer processor programs to produce compatible UADB soundings, evaluate system performance, and update the a priori developed inversion matrices. Tests with simulated data produced results significantly better than climatology.

1. INTRODUCTION

With the SSM/T temperature sounder, the United States Air Force Space and Missile Systems Organization (SAMSO) and AFGWC are continuing efforts to improve the accuracy of global atmospheric temperature soundings. The objective is to overcome the limitations of infrared radiometers by providing a better capability to recover such soundings under cloudy conditions. This is expected to contribute significantly to AFGWC weather forecasting capability.

The SSM/T software is designed to satisfy the specific requirements of AFGWC. They include requirements for the operating environment, inputs, data location, operator interaction, calibration data correction, inversion algorithm, and output products. In the operational software, the brightness temperatures are processed to yield atmospheric temperatures for mandatory pressure levels of 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20 and 10 mb; 14 thicknesses between the mandatory levels; and the temperature and pressure of the tropopause. These comprise the parameter vector defined in Section 3. The heights of the mandatory levels are computed by stacking the thicknesses on to the forecast 1000-mb height which is retrieved from the AFGWC system. These parameter data are stored in catalogued disk files prior to data transfer and archiving for diagnostic analysis and updating purposes.

To obtain these parameters, the SSM/T sounder system, developed at Aerojet Electro-Systems Company, operates in the oxygen absorption band at frequencies of 50.5, 53.2, 54.35, 54.9, 58.4, 58.825 and 59.4 GHz. The sensor is a crosstrack scanning radiometer which acquires data at 32-second intervals at 7 angular positions separated by 12 degrees. A multiple regression technique, applied after the radiation temperatures are adjusted for antenna pattern and terrain height effects, is used to invert the microwave data. The inversion matrices (one for each season, geographic zone and scan position) have been calculated from carefully selected a priori ensembles of atmospheric soundings and preflight-calibrated radiometer characteristics. Provisions are made to update and correct the inversion matrices after launch using coincident microwave and composite radiosonde/rocketsonde observations.

The SSM/T sensor system is expected to be operational in 1978. In the meantime, the software system has been developed, tested and implemented into the AFGWC system at Offutt Air Force Base, Nebraska. The tests, involving the use of simulated data, indicated that soundings will be obtained with an accuracy considerably better than estimates based on climatology.

2. SYSTEM DESCRIPTION

The SSM/T sensor system is designed to acquire microwave data simultaneously in the seven channels shown in Table I. Design specifications for these channels are also given in this table. Channel 1 is a window channel responding strongly to the earth's surface characteristics, dense clouds, and rain. It is centered at a frequency of 50.5 GHz and is used to correct the other channels for these background effects. Since the polarization dependent surface effects are removed from the brightness temperature measurements, only the atmospheric effects, which are the same for all polarizations, remain. Thus, a priori polarization corrections are avoided. To achieve this result, Channels 1-4 are required to receive the same, but arbitrary, polarization. Since Channels 5-7 are not affected by the surface, their polarization may be arbitrary. The choice of an orthogonal mode was made solely for the sensor frequency separation design requirements. Frequency stabilization, stepped automatic gain control (SAGC), and instrumentation to provide critical component temperature data are further refinements of the sensor design that have a bearing on the software.

Microwave data are acquired by means of a mechanically scanning, shrouded-reflector antenna system. The calibration and data acquisition scanning geometry are illustrated in Figure 1 and the scan parameters in Table II. A planar scan is generated by mechanically rotating the shrouded reflector perpendicular to the flight path. As shown in Figure 1, microwave data are acquired for all frequencies at seven scan positions at 12-degree angular intervals. On each scan the radiometer is calibrated; first by a 300 K warm reference load and then by sensing the cold space cosmic background (2.7 K). The scan period is 32 seconds when synchronized and 29.4 seconds when in automatic mode. Synchronization, control, clock reference, system time and source power are furnished by the DMSP spacecraft.

For each frequency, the antenna temperature, T_A , is determined in the software by the fundamental relationship

$$T_A = T_H + \frac{T_C - T_H}{V_C - V_H} (V - V_H) \quad (1)$$

where

T_H = warm calibration reference load input temperature
 T_C = cold space calibration input temperature
 V_H = output voltage during warm load calibration
 V_C = output voltage during cold space calibration
 V = output voltage corresponding to T_A

3. RETRIEVAL TECHNIQUE

The SSM/T retrieval method is based on a linear multiple regression technique. This method, developed specifically for the DMSP SSM/T application, is described briefly below. It is assumed that the deviation of the parameter vector from the climatological mean may be expressed as a linear combination of the deviations of the measured data from its mean. Thus,

$$\hat{p} - \langle p \rangle = D(d - \langle d \rangle) \quad (2)$$

where

p = atmospheric parameter vector, d = data vector
 $\hat{p}$ = predicted value of p , $\langle p \rangle$ = expected value of p
 $\langle d \rangle$ = expected value of the data vector, and D is a matrix.

Equation (2) requires the matrix D to have as many rows as p has components and as many columns as d has components. The matrix D is determined by the condition that the expected value of the square of the difference between the true value of the parameter vector p and $\hat{p}$ be a minimum. This leads to the equation

$$D = C(p - \langle p \rangle, d - \langle d \rangle) C^{-1}(d - \langle d \rangle, d - \langle d \rangle) \quad (3)$$

where $C(., .)$ denotes the covariance matrix of its two arguments.

By collecting terms, Equation (2) may be rewritten in the form

$$\hat{p} = Dd + A \quad (4)$$

where

$$A = \langle p \rangle - D \langle d \rangle \quad (5)$$

so that the predicted parameter vector is expressed as a constant A and a linear combination of the data.

To determine the covariance matrices required in Equation (3), either real time data gathered during sensor operation or a priori data may be used. Since a large number of upper air soundings, representing a wide range of meteorological conditions, have been archived over the years and the microwave response to a given atmosphere may be calculated, the latter method was considered to be more practical for implementation.

Since microwave radiometers possess inherent instrumental noise characteristics, the noise must be accounted for in the computations. This is accomplished by writing the data vector d as

$$d = d_o + \delta \quad (6)$$

where d_o is the exact value and δ a random error representing system noise with an expected value of zero. By replacing d on the right side of Equation (3) by Equation (6), the covariance matrices are found to be

$$C(p - \langle p \rangle, d - \langle d \rangle) = C(p - \langle p \rangle, d_o - \langle d_o \rangle) \quad (7)$$

$$C(d - \langle d \rangle, d - \langle d \rangle) = C(d_o - \langle d_o \rangle, d_o - \langle d_o \rangle) + C(\delta, \delta) \quad (8)$$

Equation (8) incorporates the expected instrumental noise characteristics in the computations through the noise covariance matrix $C(\delta, \delta)$.

As indicated above, the data vector d required for use in the multiple regression method is constructed from brightness temperatures. Frequencies at which the brightness temperatures are measured are chosen to respond to different atmospheric layers ranging from sea level to the 10 mb level. The resulting vertical coverage is determined by weighting functions which indicate the amount of microwave radiation arising from specific altitude regimes.

The weighting functions are defined by the following procedure. The radiative transfer equation shows that the brightness temperature may be expressed as

$$T = L \left[\epsilon T_g + (1 - \epsilon) T_{sky} \right] + T_{atm} \quad (9)$$

where

$$L = \exp \left[-\sec \theta \int_0^\infty \kappa dZ \right] \quad (10)$$

$$T_{sky} = \sec \theta \int_0^\infty \kappa T_{air} \exp \left[-\sec \theta \int_0^Z \kappa dZ \right] dZ \quad (11)$$

$$T_{atm} = \sec \theta \int_0^\infty \kappa T_{air} \exp \left[-\sec \theta \int_Z^\infty \kappa dZ \right] dZ \quad (12)$$

θ = angle with respect to earth's surface

T_{air} = air temperature at height Z

κ = absorption per unit length in the atmosphere

ϵ = emissivity of the ground

T_g = ground thermal temperature

Equations (10)-(12) are the transmission factor, the downward flowing component of the brightness temperature at the surface, and the upwelling component emitted between the earth and the microwave sensor. The contribution of the radiation emitted by the atmosphere to the temperature T is isolated from the ground component term by writing Equation (9) as

$$T = L \epsilon T_g + \int_0^{\infty} W(Z) T_{air} dZ \quad (13)$$

where $W(Z)$ is the weighting function given by

$$W(Z) = L \sec \theta \left\{ (1 - \epsilon) \exp \left[-\sec \theta \int_0^Z \kappa dZ \right] + \exp \left[\sec \theta \int_0^Z \kappa dZ \right] \right\} \quad (14)$$

The function W specifies the contribution of the atmosphere in a thickness dZ at an altitude Z to the total signal energy received. Weighting functions corresponding to the 7 SSM/T frequencies are shown in Figure 2. These are computed for an ARDC model atmosphere and a calm sea background corresponding to an incident angle of 0° using a nominal spacecraft orbit altitude of 450 nmi.

For the DMSP application a data vector was chosen to depend only on the atmospheric state. This data vector is derived from a rearrangement of Equation (9) as

$$L T_{sky} + T_{atm} = T - \epsilon T_g L \left(1 - \frac{T_{sky}}{T_g} \right) \quad (15)$$

and

$$d_i = (L T_{sky} + T_{atm}) \nu_i \quad (16)$$

where ν_i = radiometer frequencies.

Since the right-hand side of Equation (16) is not directly measurable, it must be computed from the measurements. This is made possible by the proper employment of the 50.5 GHz channel to determine ϵT_g and the lower troposphere contributions from dense clouds and rain. Thus the data vector defined in Equation (16) is a 6-component vector where ν_i are the 6 highest frequencies previously specified.

To fully understand the ramifications of the SSM/T data vector concept, Equation (9) is rewritten as

$$(\epsilon T_g)_{50.5} = \left[T - L T_{sky} - T_{atm} \right]_{50.5} / \left[L \left(1 - \frac{T_{sky}}{T_g} \right) \right]_{50.5} \quad (17)$$

specialized to 50.5 GHz. Since the same portion of the earth is viewed by all radiometer channels and with the same polarization, Equation (17) is substituted in Equation (15) to provide a measured data vector defined as

$$d_i = T_{\nu_i} - (T_{50.5} - s_{50.5}) a_{\nu_i} \quad (i = 1, 2, \dots, 6) \quad (18)$$

where

$$s_{50.5} = \langle L T_{sky} + T_{atm} \rangle_{50.5}$$

and

$$a_{\nu_i} = \left\langle L \left(1 - \frac{T_{sky}}{T_g} \right) \right\rangle_{\nu_i} / \left\langle L \left(1 - \frac{T_{sky}}{T_g} \right) \right\rangle_{50.5} \quad (i = 1, 2, \dots, 6)$$

These expected values are computed from the same a priori data used to determine the covariance matrices.

When these equations are applied to the form of the multiple regression method described by Equations (4) and (5), the estimate of the parameter vector p is given by

$$\hat{p} = S T_B + A' \quad (19)$$

where $S = (-Da^!D)$ is a matrix whose first column is $-Da$ and whose remaining columns are the columns of D ,

$$T_B = \begin{pmatrix} T_{50.5} \\ \vdots \\ T_{59.4} \end{pmatrix}$$

and

$$A' = \langle p \rangle - D \langle d \rangle + s_{50.5} \text{ Da}$$

In summary this retrieval technique contains elements which depend mainly on the atmosphere not on the background. It is equally valid over land, water or mixed surface conditions. In contrast to the ground, the atmosphere emits unpolarized radiation so that the received polarization is no longer a factor in the data processing. The data processing does provide, however, corrections for antenna pattern and terrain height effects. These are described below.

Antenna pattern corrections are applied to the antenna temperatures directly after calibration to yield brightness temperatures. The method consists of scaling the antenna temperature $T_A(\nu_i, \theta_j)$ by a factor g_e which is the fraction of the total gain of the antenna intercepting the earth, to produce the brightness temperature.

$$T_B(\nu_i, \theta_j) = T_A(\nu_i, \theta_j) / g_e(\nu_i, \theta_j) \quad (20)$$

A total of 49 factors are used, one for each frequency and scan angle.

Since the inversion matrices are computed only for sea level surface conditions, adjustments to the brightness temperatures determined above must be made for measurements taken over elevated terrain. This adjustment is necessary because the brightness temperatures measured by the lower microwave frequency channels may differ significantly from temperatures which would arise were the same surface at sea level. The effect caused by the missing portion of the atmosphere requires an adjustment to the brightness temperatures prior to inverting. The adjustment is derived from Equations (9) and (17) as

$$T_o(\nu) = T_l(\nu) + \Delta_a - \epsilon T_g \Delta_b \quad (21)$$

where

$$\Delta_a(\nu) = \langle T_{\text{atm}} + L T_{\text{sky}} \rangle_o - \langle T_{\text{atm}} + L T_{\text{sky}} \rangle_l \quad (22)$$

$$\Delta_b(\nu) = \left\langle L \left(1 - \frac{T_{\text{sky}}}{T_g} \right) \right\rangle_l - \left\langle L \left(1 - \frac{T_{\text{sky}}}{T_g} \right) \right\rangle_o \quad (23)$$

and

$$\epsilon T_g = \left[T_{l, \nu=50.5} - s_{50.5} + \Delta_a(50.5) \right] / \left[\left\langle L \left(1 - \frac{T_{\text{sky}}}{T_g} \right) \right\rangle_{o, \nu=50.5} + \Delta_b(50.5) \right] \quad (24)$$

In these equations, the subscript l represents the true atmosphere and surface at height h while o represents the true atmosphere above h and an intervening atmosphere which is determined statistically between sea level and h. The quantities $s_{50.5}$ and the first term in the denominator of Equation (24) have been defined in Equations (18) and (17) respectively. The factors $\Delta_a(\nu)$ and $\Delta_b(\nu)$ are computed only for Channel 1 to 4 frequencies since the three highest frequency channels are unaffected by the terrain. These factors are determined by the characteristics of the atmosphere comprising the statistical data ensembles. Quadratic functions were found to fit the data satisfactorily. Specifically, for each of the low channels

$$\Delta_a = A_a h + A_b h^2 \quad (25)$$

and

$$\Delta_b = B_a h + B_b h^2$$

where h is the terrain height and the constants A_a , A_b , B_a , B_b are regression values determined from the data base ensembles.

The SSM/T software contains provisions to correct the a priori D-matrices during the operational phase to optimize the retrieved data when necessary. The procedure consists of comparing SSM/T derived soundings with coincident radiosonde soundings. The implemented update procedure corrects for sensor and atmospheric modeling bias errors. A linear

regression is performed between the measured data vector and a data vector calculated from coincident composite radiosonde and rocketsonde observations. Regression coefficients α_i and β_i are computed for the i th frequency by

$$d_m = \alpha d_c + \beta \quad (27)$$

where d_m is the measured data vector and d_c the calculated data vector. These coefficients are used to update the a priori correlation matrices (indicated by the subscript a) and the expected data vector $\langle d_a \rangle$ to yield updated quantities (indicated by the subscript u) as shown in Equations (28)-(31)

$$\alpha = \begin{pmatrix} \alpha_1 & 0 & 0 \\ 0 & \alpha_2 & 0 \\ 0 & & \end{pmatrix} \quad \beta = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \vdots \end{pmatrix} \quad (28)$$

$$C(p - \langle p \rangle, d_u - \langle d_u \rangle) = C(p - \langle p \rangle, d_a - \langle d_a \rangle) \alpha \quad (29)$$

$$C(d_u - \langle d_u \rangle, d_u - \langle d_u \rangle) = \alpha C(d_a - \langle d_a \rangle, d_a - \langle d_a \rangle) \alpha \quad (30)$$

$$\langle d_u \rangle = \alpha \langle d_a \rangle + \beta \quad (31)$$

These updated matrices are combined with an operationally determined error covariance matrix, $C(\delta, \delta)$, to yield new matrices defined by

$$D = C(p - \langle p \rangle, d_u - \langle d_u \rangle) \left[C(d_u - \langle d_u \rangle, d_u - \langle d_u \rangle) + C(\delta, \delta) \right]^{-1} \quad (32)$$

4. DATA PROCESSING

4.1 GENERAL DESCRIPTION

Ephemeris data are merged with the raw microwave sensor data and DMSP system data at AFGWC to form the required input files for processing. The SSM/T data processing consists of four main computer program components labeled PROCESSOR-A, PROCESSOR-B, MICRO-CHECK, and D-UPDATE. Only PROCESSOR-A and PROCESSOR-B are designed to operate in real time. PROCESSOR-A is fundamentally a preprocessor for PROCESSOR-B, the inversion processor. MICRO-CHECK is an on-line program, operating once each day as a preprocessor for the update program, D-UPDATE. Both MICRO-CHECK and D-UPDATE are designed to evaluate and correct the a priori D-matrices. Each of these processing programs consists of a driver routine and numerous subroutines. They are described in the following section in reference to the top level flow diagram shown in Figure 3.

4.2 PROCESSOR-A

PROCESSOR-A is designed to process data contained in the input file PROD*AEROJET-MDATA while retrieving required information from various AFGWC data base components. The processing is initiated at the UNIVAC 1110 system console by operator keyboard input. Data are read in convenient groups from the input file to minimize input/output operations. Raw data, in digital counts, are processed to produce the SSMT*BRTEMP file, SSMT*-CALGAIN file, and various page print diagnostics. SSMT*BRTEMP file serves as the main input to PROCESSOR-B whereas SSMT*-CALGAIN is generated for off-line operational analysis and system evaluation. The diagnostics are produced for error analysis purposes to aid in the recovery of possible program failures. As depicted in Figure 3, valid sensor data are stripped from the input file and identified for each spacecraft. These data are calibrated, corrected for antenna patterns, timed, and earth-located. Gross error checks are made to the corrected brightness temperatures against fixed upper and lower limits. Corresponding terrain heights and 1000-mb heights are retrieved from appropriate elements in the AFGWC data base. The corrected brightness temperatures and associated view data are stored in

the SSMT*BRTEMP file while validated raw data are stored in the SSMT*CALGAIN file. Page-print diagnostics may be generated for this processor by the operator. PROCESSOR-A executes automatically processing one or more orbits of data from the input file which may contain a maximum of 24 hours of data. After PROCESSOR-A executes, further real-time processing is continued in PROCESSOR-B

4.3 PROCESSOR-B

PROCESSOR-B runs sequentially to PROCESSOR-A in an automatic mode with the processing mode and area limits keyed in by the operator. Processing involves reading data from the SSMT*BRTEMP file, selecting data for appropriate views (scan position), testing for the likelihood of dense clouds or rain (over oceans only), adjusting for terrain height and inverting to obtain atmospheric temperature soundings. The inversion process is described in Section 3. All a priori D-matrices are stored in the SSMT*D-MATRICES file. There are 48 D-matrices in all, including one each for three geographic zones (tropics, mid-latitudes and arctic/antarctic), four seasons, and four scan positions. The recovered soundings are stored in the SSMT*SOUNDINGS file and SSMT*VERIFICATION file. The corresponding brightness temperatures are also stored in the SSMT*VERIFICATION file. In addition PROCESSOR-B produces page-print diagnostics of files as well as the location of views having dense clouds or rain. After processing the last view of the SSMT*BRTEMP file, PROCESSOR-B provides a listing of the number of soundings processed prior to termination.

4.4 MICRO-CHECK

The MICRO-CHECK program is designed to run once each day. Inputs to MICRO-CHECK are derived from the SSMT*VERIFICATION and AFGWC UADB. MICRO-CHECK searches the UADB for radiosonde observations coincident with the inverted SSM/T soundings. It computes the residual errors between the SSM/T soundings and the coincident radiosonde observation. The residual error data are used to evaluate the overall performance of the retrieved profiles. Coincident rocketsonde soundings are also found. When rocketsonde and radiosonde observations are found to be coincident with an SSM/T sounding, they are quality tested and combined to produce a single sounding extending from sea level to the 0.5-mb level. This composite sounding is then used to calculate the data vector. The measured data vector is also determined. These data vectors are finally stored in the SSMT*SSMTSTATFILE file with the residual error data and the number of coincident data vector pairs. The SSMT*SSMTSTATFILE file is used also as an input to MICRO-CHECK and successively updated each day with new data. MICRO-CHECK also contains provisions for print-plotting coincident SSM/T and radiosonde soundings and listing the statistical data. MICRO-CHECK runs to completion when all soundings in the UADB are processed.

4.5 D-UPDATE

Periodically, depending on the number of coincident measurements found in MICRO-CHECK, the D-UPDATE program is executed. It runs automatically with input data from SSMT*SSMTSTATFILE. Using the data input from this file, D-UPDATE tests the data for sample-size representativeness and distribution in temperature. If these tests are satisfactorily passed, an OPTION 1 update may be executed. New D-matrices are generated, tested in PROCESSOR-B and used operationally if warranted. After five successive OPTION 1 updates, tests of OPTION 2 may be performed to determine if the sensor bias and random errors exceed the threshold values. When they exceed threshold values, an OPTION 2 update is executed by modifying the correlation matrices, testing them in PROCESSOR-B, and replacing operational D-matrices with the newly developed ones.

5. RESULTS

The SSM/T software has been implemented, tested and verified in the AFGWC UNIVAC 1110 system using simulated data in the input file PROD*AEROJETMDATA. These data were computed from an independent set of soundings selected from the World Data Center A and Eastern Meridional high-altitude meteorological soundings. Data were selected for all stations in these networks and stratified by latitude and season to complete a nominal DMSP orbit. A total of 192 soundings were used in the simulation with 1344 views. Each view was assigned latitude and longitude coordinates, surface height, surface temperature and emissivity value (over land) or salinity value (in parts per thousand) for views located over the ocean. Antenna temperatures were computed for each channel frequency and input to a simulator program

with sensor and system data to generate the input file for test and verification purposes. Several versions of this file were generated by the simulation program to test and verify various system mode characteristics. The inverted soundings produced in the normal processing mode were compared to original source reference data by a separate subroutine for 2 seasons and 6 geographic zones. These included the arctic, mid-latitude, and tropic spring in the Northern Hemisphere, and the antarctic, mid-latitude, and tropic fall in the Southern Hemisphere.

The results, obtained from comparing 224 inverted soundings with the source reference soundings in each geographic zone, are shown in Figure 4. The standard deviation of the 224 soundings in each zone-season are also shown in this figure. As shown in Table I, the SSM/T sensor can measure brightness temperatures averaged over the weighting functions shown in Figure 2 with an rms accuracy of 0.4 to 0.6 K for integration time of 2.7 seconds. The results shown in Figure 4 indicate the SSM/T rms uncertainty averaged over the 15 mandatory levels is of the order of 2 K. Larger uncertainties occur at the 1000-mb heights since the inferred soundings are biased to the 1000-mb forecast height. A qualitative comparison of the rms uncertainty in the inferred soundings with the standard deviation of the source soundings reveals that soundings will be obtained from the SSM/T measurements with an accuracy considerably better than estimates based on climatology.

TABLE I. CHANNEL PARAMETER DESIGN SPECIFICATIONS

Channel	Polarization	Frequency (GHz)	Bandwidth (MHz)	NETD (°K)
1	} Principally Horizontal	50.5	400	0.6
2		53.2	400	0.4
3		54.35	400	0.4
4		54.9	400	0.4
5	} Orthogonal to Channels 1-4	58.4	115	0.5
6		58.825	400	0.4
7		59.4	250	0.4

TABLE II. SCAN PARAMETERS

Scan Type	Cross-Track Nadir
Cross-Track Positions	7
Calibration Positions	2-Cold Space and 300°K
Instantaneous Field of View	14°
Total Cross-Track Scan	36°
Total Scan Period	32 Seconds
Integration Time (Cross-Track and Calibration Positions) . .	2.7 Seconds
Sync Mode	Auto Mode or On-Sync

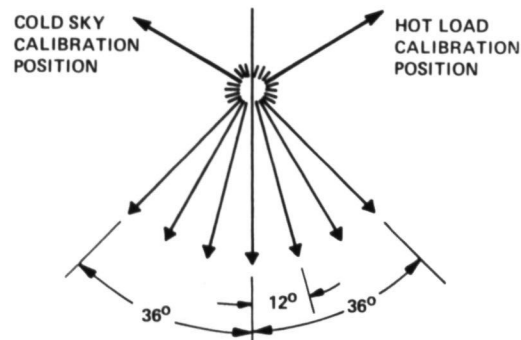


FIGURE 1. Scan Geometry

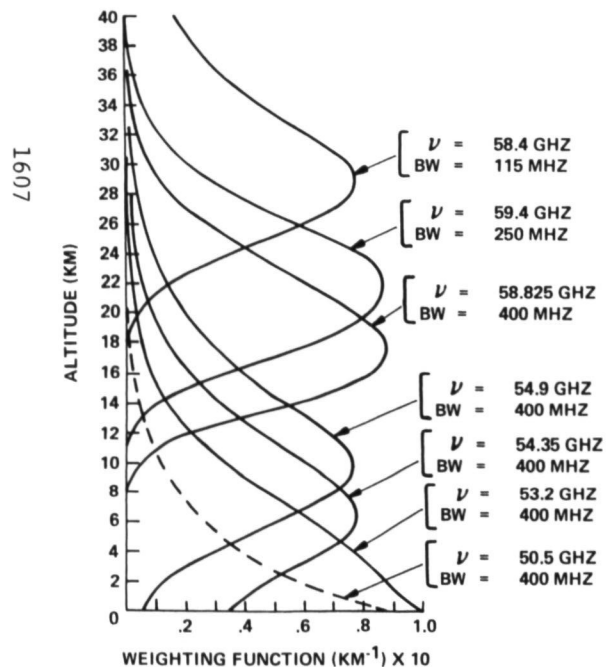


FIGURE 2. Weighting Function, $\theta = 0^\circ$, Calm Sea Background

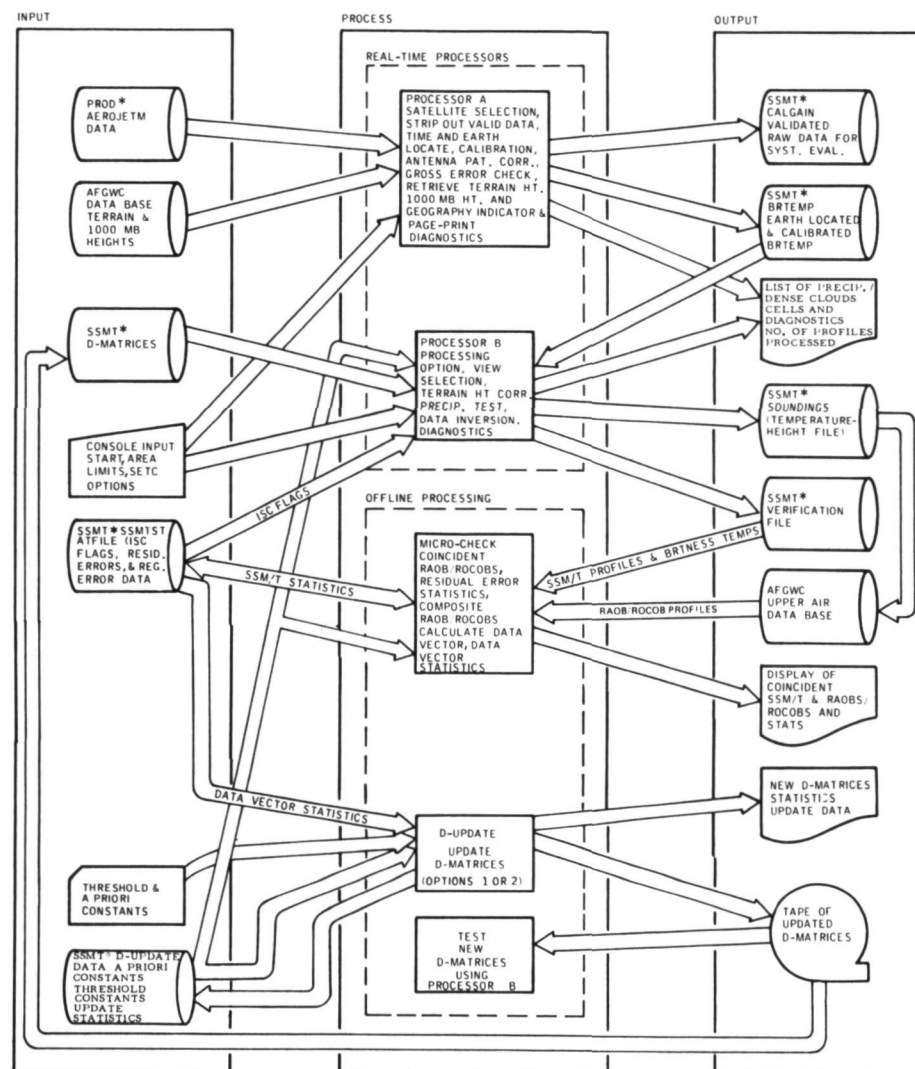
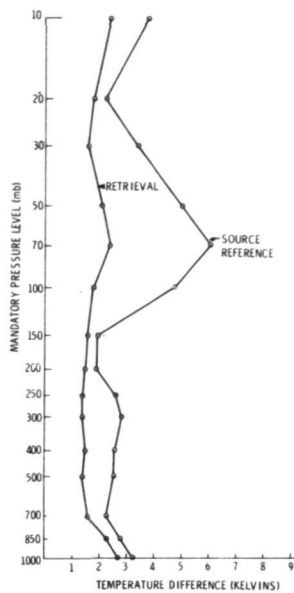
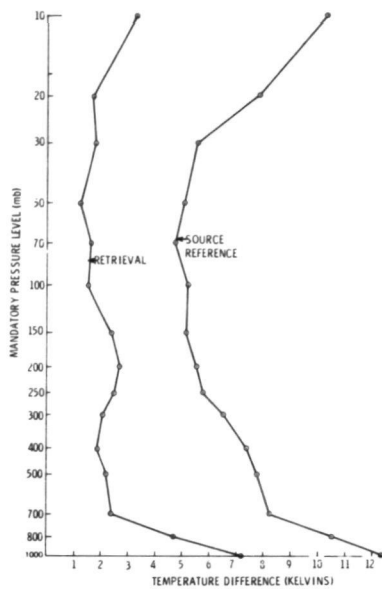


FIGURE 3. SSM/T Software Diagram

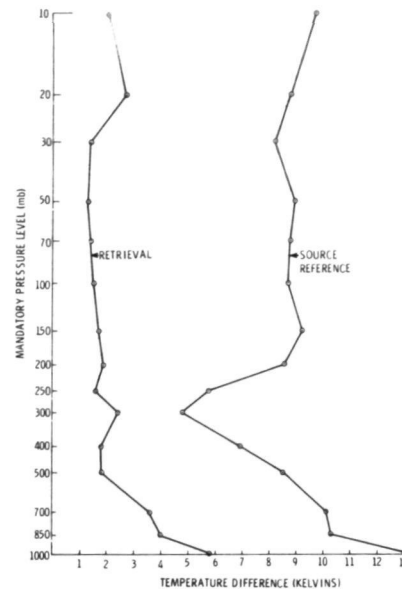
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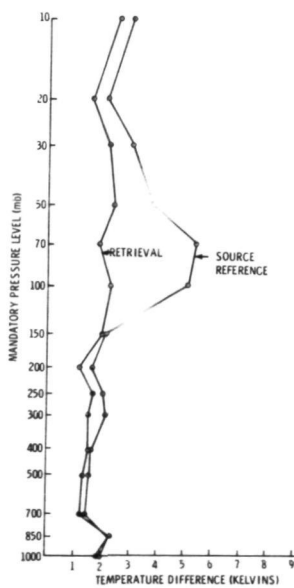
A. Tropic Spring
Northern Hemisphere



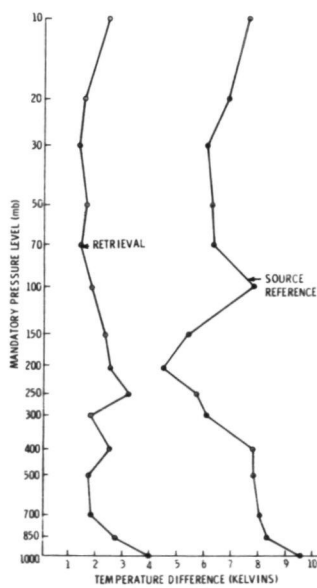
B. Mid-Latitude Spring
Northern Hemisphere



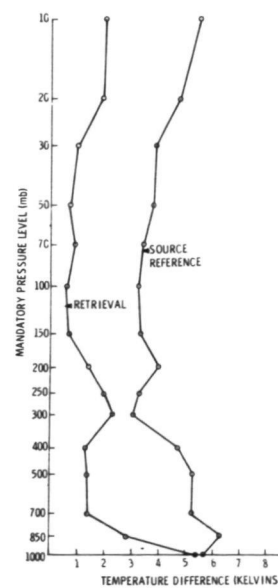
C. Arctic Spring
Northern Hemisphere



D. Tropic Fall
Southern Hemisphere



E. Mid-Latitude Fall
Southern Hemisphere



F. Antarctic Fall
Southern Hemisphere

FIGURE 4. RMS Errors in SSM/T Retrievals and Variations in Source Reference

SURFACE TEMPERATURES AND TEMPERATURE GRADIENT FEATURES
OF THE U.S. GULF COAST WATERS

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ABSTRACT

Satellite thermal infrared data on the Gulf of Mexico show that a seasonal cycle exists in the horizontal surface temperature structure. In the fall, the surface temperatures of both coastal and deep waters are nearly uniform. With the onset of winter, atmospheric cold fronts, which are accompanied by dry, low-temperature air and strong winds, draw heat from the sea. Penetrative convection and wind-driven mixing lower temperatures, first in the shallowest waters and then, as the winter season progresses, in deeper and deeper portions of the Gulf. A band of cooler water forming on the inner shelf expands, until a thermal front develops seaward along the shelf break between the cold shelf waters and the warmer deep waters of the Gulf.

Digital analysis of the satellite data has been carried out in an interactive mode using a minicomputer and software developed at the Coastal Studies Institute. A time series of temperature profiles illustrates the temporal and spatial changes in the sea-surface temperature field.

1. INTRODUCTION

The most fundamental property of coastal and shelf waters routinely available from remote-sensing systems is temperature. The data are limited to surface temperatures only, but the prominent surface expression of important processes (coastal oceanic fronts, river and estuarine discharge plumes, and conditions of strong vertical mixing) make these data fields particularly useful.

A series of images acquired by the NOAA satellites has been obtained (in image and tape format). The images span the time from early fall to mid-spring. These data are products of the thermal sensors in the Very High Resolution Radiometers (VHRR). The spatial resolution of these scanners is 0.9 km at the satellite subpoint and degrades to 1.5 km at the image margin. Maximum thermal resolution is 0.5K. Thermal infrared images of any particular area are acquired every 12 hours, and a visual image is acquired once every 24 hours. In all the images the warmer-scene temperatures are represented by the darker gray shades. The data reveal the response of the coastal waters to the passage of winter-season atmospheric cold fronts.

The satellite data show highly organized patterns of surface temperatures, strong thermal fronts, and many complex gradient features. River and estuarine discharges, coastal and shelf waters, offshore gulf water, and the Loop Current show up as thermally differentiated water masses. The Loop Current is the stream of warm equatorial water that enters the Gulf of Mexico through the Yucatan Channel. After entering the Gulf it makes a broad curved 180° turn, exits through the Straits of Florida, and becomes a source of the Gulf Stream. With the exception of the thermally conservative Loop Current and the already chilled riverine discharges, the coastal and continental shelf waters undergo

important changes. These are primarily alterations in horizontal and vertical temperature structure initiated by the cold, dry continental air behind the atmospheric polar fronts. The coldest waters occur in the estuaries and along the inner shelf; the waters become progressively warmer offshore in the deeper portions of the Gulf. The shallow waters of the shelf are generally well mixed and the sea surface temperature is the same as that of the vertically uniform water column (Etter and Cochrane, 1975). The fall and spring months are times of transition between these two extremes of heat content and surface temperature gradients.

Figure 1 is an outline map of the Gulf of Mexico. The location of the continental shelf break is indicated along the northern coast of the Gulf by the 100-meter depth contour.

2. DISCUSSION

The NOAA-5 image for 1 October 1976 (Fig. 2) shows the conditions that are typical of the summer season. The surface temperatures of the coastal bays and shelf waters are the same as the temperature of the deep water of the Gulf of Mexico. Historical oceanographic data show that subsurface temperatures during the warm summer months are also uniform horizontally (Etter and Cochrane, 1975). By 11 October 1976 (Fig. 3) the first major cold front of the season had moved across the Gulf Coast. The air behind this front was much colder, and nighttime temperatures up to 7.5°C lower than those prevailing earlier in the season were measured at several coastal weather stations. The result of this initial outbreak of cold air was the lowering of the surface temperature of the coastal lakes and bays. The cool estuarine discharge of plumes overrunning the still-warm inner shelf waters shows up on the imagery; the maximum thermal contrast occurs at this point in the winter season. Offshore, horizontal temperature gradients still remained very weak. Along the shelf east of the Mississippi River the warm offshore water extended to the coast. West of the Mississippi River, cooler water was present tens of kilometers offshore. This difference between the regions east and west of the river is a consequence of the much shallower water on the shelf along the Louisiana coast. As a cold, dry air mass passes over the Gulf waters, energy is transferred from the ocean. Long-wave radiation is readily transmitted through the clear skies into space. Sensible and latent heat transferred to the atmosphere by conduction and evaporation at the water surface are carried upward by turbulent air motions. Persistent offshore winds sweep this heat and water vapor seaward, and dry air is replenished from the land. Aided by the wind stress, the increase in density of surface waters resulting from heat loss and evaporative salinity increase initiates penetrative convective mixing, which dissipates stratification, and the surface temperatures become more representative of the resulting isothermal water column. Because the amount of temperature decrease depends upon depth, the shallowest regions experience the largest temperature drop. Surface temperature profiles extracted from the digital tapes for the NOAA-5 image of 11 October 1976 are shown in Figure 4. Figure 4a is the profile of line A-A' in Figure 3. Three temperature regions are evident: the cold bay waters, the slightly warmer nearshore waters, and the as yet uncooled offshore waters. The profile (B-B') from the Florida coast (Fig. 4b) shows the relatively uniform surface temperatures. Note that no attempt has been made to correct the satellite-observed temperatures for atmospheric attenuation.

The next phase, the winter cycle, is represented by an image taken on 18 January 1977 (Fig. 5). At the time this image was acquired the coastal waters of the Florida shelf had cooled and a temperature front was situated approximately 30 km offshore. The cooling of the water column that had occurred much earlier west of the Mississippi was beginning along the Florida coast. Figure 6 contains the surface temperature profiles extracted from the NOAA-5 image of 18 January 1977. Two temperature regions are evident in this image along the Florida coast (profile B-B'): cooled nearshore waters and the still-warm offshore waters.

With the passage of a succession of cold fronts, the band of cooler inner shelf waters forming along the coast expands until an oceanic thermal front

develops between the cold shelf waters and the warmer deep Gulf waters approximately along the 100-meter isobath (Fig. 1). This condition is illustrated by the NOAA-3 image of 13 February 1976 (Fig. 7). The synoptic sea surface temperature pattern at this time was divided into three distinct zones: the cold shelf waters, the warmer open Gulf waters, and, warmest of all, the Loop Current. Mesoscale irregularities had developed along the thermal front between the shelf waters and those of the open Gulf. The origin of these features is as yet unclear. Possible mechanisms include horizontal eddy motion, intrusions of surface water driven by strong winds, and overrunning by strong offshore currents. Another possible cause of excursions of the warmer water toward the coast could have been internal density cascading. This process involves down-slope flow of the colder and hence denser water that had formed on the shelf and a compensating landward flow of warmer offshore surface water. The shallow water of the Bahama Banks had also been cooled and was distinctly outlined in this image. The profiles in Figure 8 are taken from the NOAA-3 image of 13 February 1976. Profile A-A', from off the Louisiana coast, shows evidence of three temperature regions. The profile from off the Florida coast (B-B') is more complex owing to the presence of the mesoscale irregularities, as seen in Figure 7.

The continued outbreaks of polar continental air masses over the Gulf during the winter of 1976-77 caused the temperature patterns of the Gulf waters to evolve an additional step. By 1 March 1977 (Fig. 9) the gradient between the shelf and the deep Gulf waters had broken down. Strong cold fronts had significantly chilled the entire northern part of the Gulf, and only the equatorial waters of the Loop Current remained warm.

As the strength of the polar air masses decreases, with the advent of spring, the Gulf water begins to warm. The first waters that respond to the warming trend are the shallow waters in the coastal lakes and bays and along the shoreline. The NOAA-3 image of 24 April 1976 (Fig. 11) shows this warming along the Florida coast. The surface temperature of the bays along the northwest coast was warmer than that of the nearby Gulf water. The shallow banks in the Bahamas also had higher sea-surface temperatures than the adjacent Atlantic Ocean water. As the length of the days increases and the air temperatures rise, the waters of the Gulf will return to the warm-season conditions of Figure 1.

3. CONCLUSIONS

1. Surface temperature patterns of the Gulf of Mexico display a highly organized character. During the winter months three distinct regions are present: the cold shelf waters, the warmer deep Gulf waters, and the equatorial waters of the Loop Current.

2. A seasonal cycle of progressive cooling changes the uniform surface temperature distribution of the summer months into the thermally structured surface of the winter season.

3. The locations of the thermal oceanic fronts are controlled by the bathymetry; the shallowest areas cool quickest.

4. The shallow coastal lakes and bays are the first areas to show a response to both heating and cooling and therefore serve as indicators of the direction of the heat fluxes between ocean and atmosphere.

5. Poorly understood mesoscale irregularities occur along the oceanic thermal fronts. Sources of these features are uncertain because of the coarse spatial and temporal resolution of previous oceanographic measurements.

6. Surface measurement programs, guided by real-time satellite infrared

observations, are suggested to aid in resolving the sources of frontal irregularities.

7. During the winter season the Loop Current is readily discernible because of the maximum thermal contrast that exists between it and the adjacent Gulf water.

ACKNOWLEDGMENTS

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REFERENCE

Etter, P. C., and J. C. Cochrane, 1975, Water temperature on the Texas-Louisiana shelf. Texas A & M Marine Advisory Bulletin TAMU-SG-75-604.



FIGURE 1. THE GULF OF MEXICO. The location of the continental shelf break is indicated by the 100-meter depth contour.

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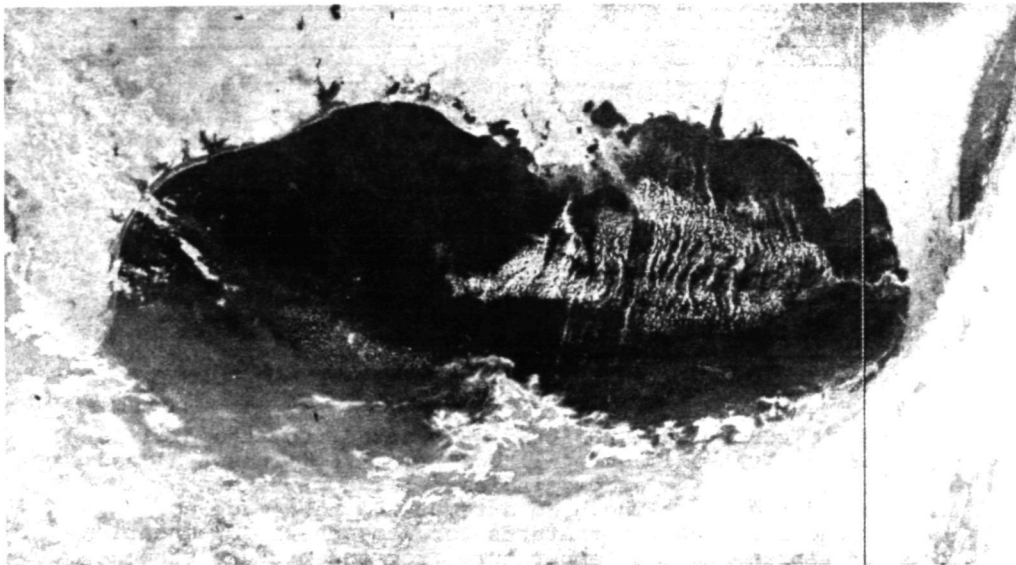


FIGURE 2. NOAA-5 INFRARED IMAGE, ORBIT 785, 1 OCTOBER 1976, 0225Z. Acquired shortly after the passage of an early-season cool front. Surface temperatures of coastal and deep waters are uniform; no strong thermal gradients exist. This image is representative of summer conditions.

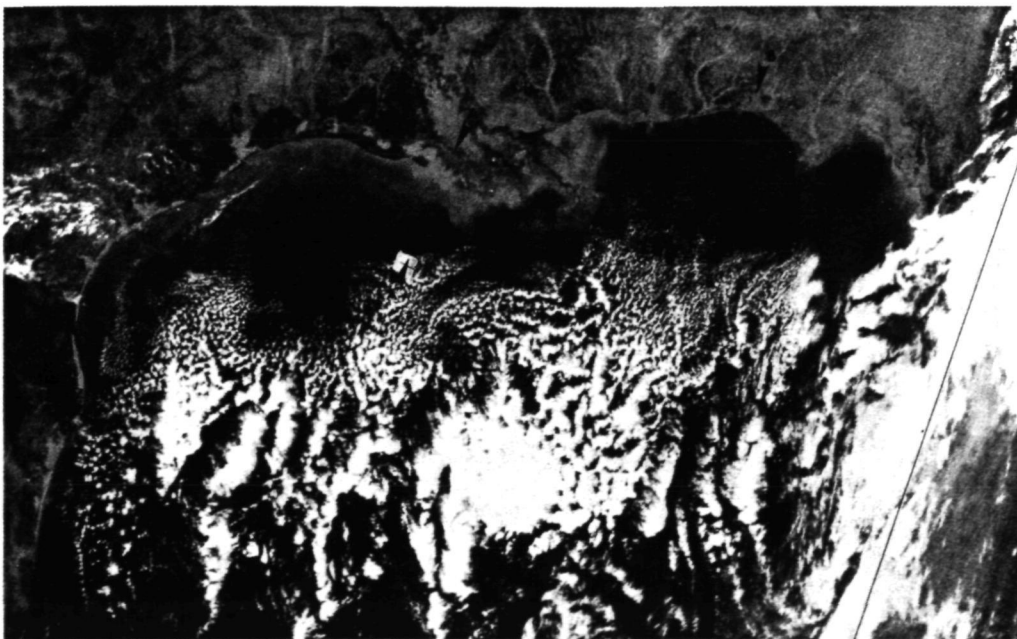


FIGURE 3. NOAA-5 INFRARED IMAGE, ORBIT 915, 11 OCTOBER 1976, 1500Z. Acquired after the first strong cold front of the season. Coastal lakes and bays chilled. Estuarine discharge plumes thermally distinct. Offshore cooling along Louisiana coast and weak horizontal temperature gradients.

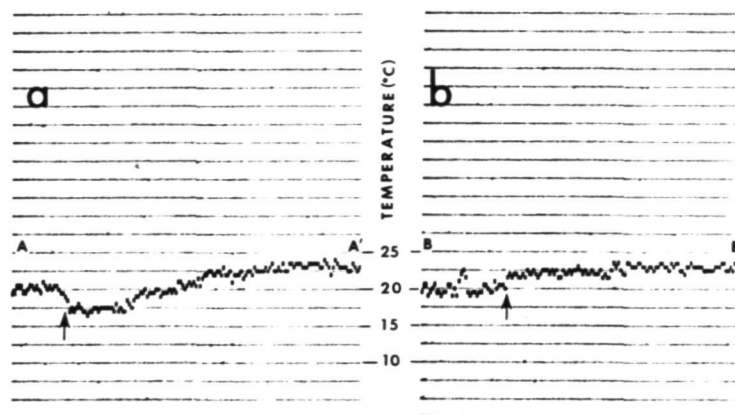


FIGURE 4. TEMPERATURE PROFILES. Extracted from the digital data for the NOAA-5 image of 11 October 1976 (lines A-A' and B-B' in Fig. 3). The arrows indicate the approximate location of the coastline. No attempt has been made to correct the observed temperatures for atmospheric attenuation. Each dot represents the temperature from one picture element along the lines.



FIGURE 5. NOAA-5 INFRARED IMAGE, ORBIT 2134, 18 JANUARY 1977, 0204Z. Sharp thermal gradient formed off Florida coast as a result of heat loss by the shallow water column. Continuation of offshore cooling.

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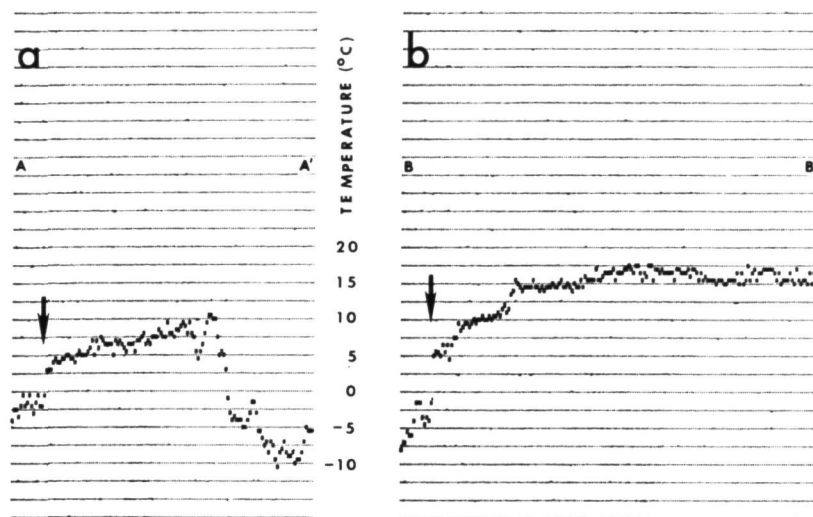


FIGURE 6. TEMPERATURE PROFILES. Lines A-A' and B-B' in Figure 5. Extracted from the digital data for the NOAA-5 image of 18 January 1977. The temperatures off the Florida coast (Fig. 6b) show the effect of the negative heat fluxes. Waters near the coast are cooler than those offshore, where depth is greater. Temperatures off the Louisiana coast are also cooler nearshore, but there is no sharp gradient offshore. Location of the coastline is indicated by the arrows.



FIGURE 7. NOAA-3 INFRARED IMAGE, ORBIT 10267, 13 FEBRUARY 1976, 0157Z. Strong negative heat fluxes affect the entire Gulf region, including the Bahamian and Cuban banks. Water in all shallow regions becomes cold. Three water types defined: cold shelf and coastal waters, cool Gulf waters, and warm equatorial waters in the Loop Current and Gulf Stream.

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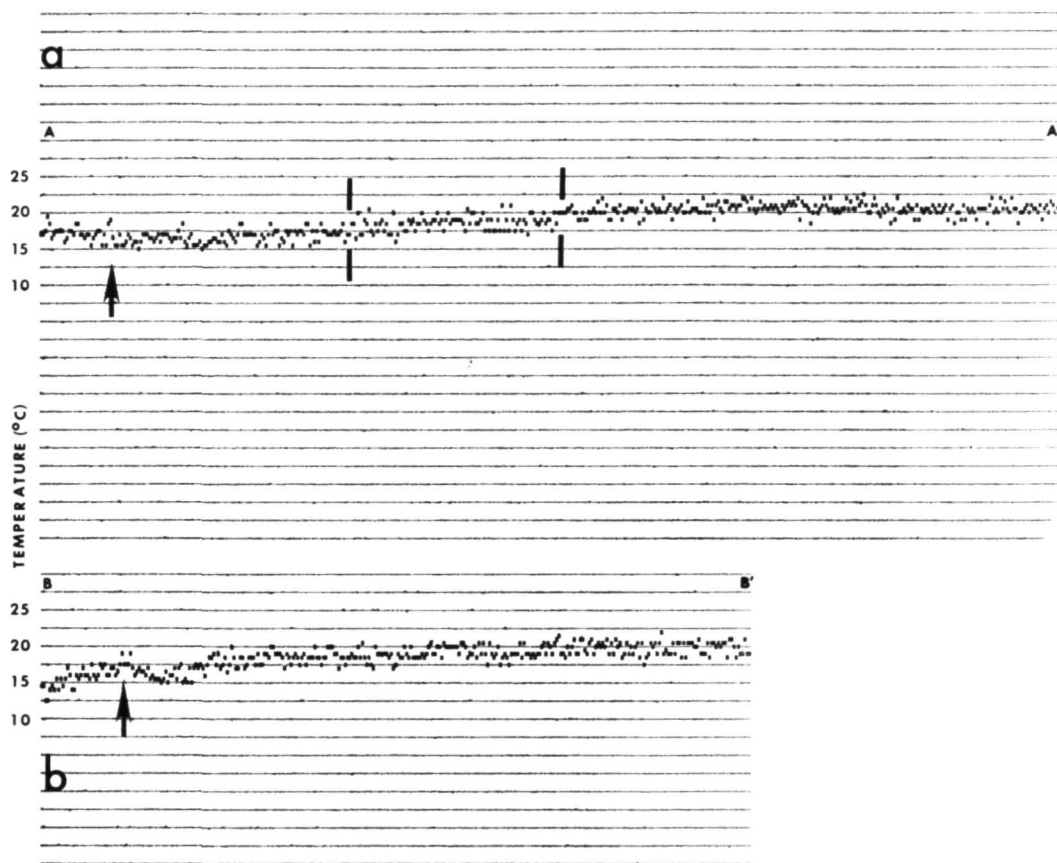


FIGURE 8. TEMPERATURE PROFILES, Lines A-A' and B-B' in Figure 7. Extracted from the digital data for the NOAA-3 image of 13 February 1976. The two vertical lines in profile A-A' approximate the locations of the gradients between the three temperature regions that are evident off the Louisiana coast (Fig. 7). Off the Florida coast (profile B-B') there does not seem to be such a separation. Location of the coastline is indicated by the arrows.



FIGURE 9. NOAA-5 INFRARED IMAGE, ORBIT 2654, 1 MARCH 1977, 0218Z. Strong cold fronts of the severe winter continue to cool shelf and Gulf waters, and thermal contrast at the shelf decreases. Eddies from the Loop Current extend far to the north.

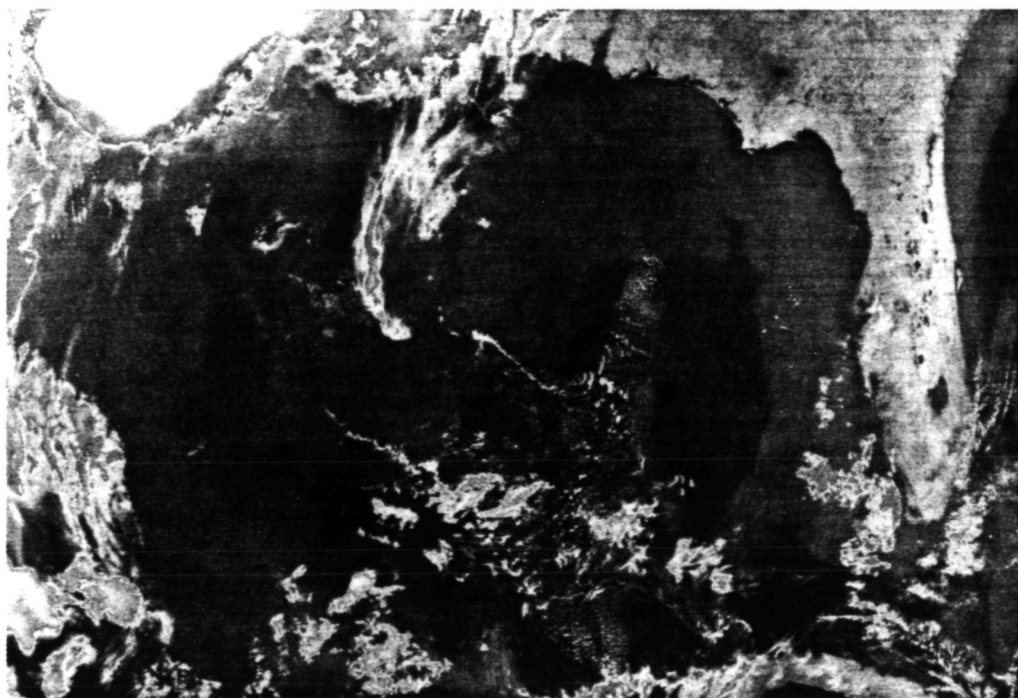


FIGURE 10. NOAA-3 INFRARED IMAGE, ORBIT 11085, 19 APRIL 1976, 0158Z. Warming of shallow regions along the Florida coast; evidence of positive heat flux along the inner shelf.

MULTISPECTRAL ANALYSIS OF OCEAN DUMPED MATERIALS

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ABSTRACT

Experiments conducted in the Atlantic coastal zone indicate that plumes resulting from ocean dumping of acid wastes and sewage sludge have unique spectral characteristics. Remotely sensed wide area synoptic coverage provides information on these pollution features that is not readily available from other sources. Aircraft remotely sensed photographic and multispectral scanner data were interpreted by two methods. First, qualitative analyses in which pollution features are located, mapped, and identified without concurrent sea truth and, second, quantitative analyses in which concurrently collected sea truth is used to calibrate the remotely sensed data and to determine quantitative distributions of one or more parameters in a plume.

Location and mapping of pollution features in the coastal zone previously have been based on radiance differences between the plumes and receiving waters, using sea truth or other data for identification. As a result of the data analyses in these experiments, an in-scene calibration technique was developed that "normalizes" atmospheric effects, thereby potentially providing a means of plume identification that is independent of the specific scene and the multispectral scanner used. The in-scene calibration technique is based on ratio values in each band of a multispectral scanner where the ratios are radiance values in the pollutant plume divided by radiance values of ocean water in the same scene. Application of this technique to data from several experiments indicates that plumes resulting from acid wastes and sewage sludge have distinctive spectral characteristics over a range of environmental conditions and for two multispectral scanners flown at altitudes of 3.0 and 19.7 kilometers.

In addition to qualitative analyses that used the in-scene calibration, quantitative analysis techniques were applied to sewage sludge dump plumes. Results indicated that quantitative relationships exist between suspended solids in the plumes and remotely sensed radiance values. The calibrated regression equation that used Modular Multispectral Scanner bands 4 (540-580 nanometers (nm)) and 9 (760-860 nm) had a correlation coefficient of 0.961 and a standard error of estimate of 4.11 mg/l for a measured range from 1.11 to 32.20 mg/l. The calibrated regression equation was applied to map quantitative distributions of suspended solids in two plumes in the remotely sensed scene.

Additional experiments will be required to more fully define the role of remote sensing for monitoring ocean dumping and for determining plume characteristics, such as dispersion coefficients.

1. INTRODUCTION

Pollution features in coastal zones include plumes from ocean dumping of waste materials, such as sewage sludge and acid wastes. It is of interest to environmental managers to locate these plumes and determine the pollutant dispersion characteristics. Remotely sensed wide area synoptic coverage provides information on features in the coastal zone that is not readily available by other means. Remotely sensed data may be interpreted by two approaches. The first approach is qualitative in nature and has been used to map features, such as river plumes, without concurrent sea-truth measurements. Photographic and multispectral scanner imagery or digital data have been used in conjunction with other available data, following photoanalysis techniques. The second approach is quantitative analyses in which sea truth collected at a limited number of locations is used to calibrate remotely sensed digital data and to extend the results to the remotely sensed scene. Results of the quantitative analyses, calibrated regression equations, have been used to develop maps showing quantitative distributions of one or more water quality parameters, such as suspended solids or chlorophyll a.

Aerial photographs have been analyzed by Scherz (ref. 1) to locate and trace pollutant plumes and their dispersion characteristics. Klemas, et al. (ref. 2) have analyzed Landsat and Skylab multispectral scanner imagery and/or photographs to study sediment distributions, acid waste plume persistence, and other characteristics of coastal zone pollution features. Yarger, et al. (ref. 3), Williamson and Grabau (ref. 4), Klemas, et al. (ref. 5), Rogers, et al. (ref. 6), and Johnson (refs. 7, 8, and 9) have applied classification or regression techniques to calibrate Landsat and aircraft multispectral scanner data and to map distributions of water quality parameters in inland and estuarine systems.

More recently, experiments were conducted in the Atlantic coastal areas to determine the applicability of aircraft remote sensing systems to (1) locate, identify, and map plumes resulting from ocean dumping of acid waste and sewage sludge, and (2) evaluate previously developed quantitative analysis techniques for determining quantitative distributions of materials in sewage sludge dumps. These investigations include development of multispectral analysis techniques that may be used to identify ocean dumped materials over a range of environmental conditions.

It is the purpose of this paper to present results from these experiments and the associated data analysis investigations. Results of the qualitative analyses are applicable to the technology base that is required before a remotely sensed monitoring system can be developed, for areas such as the New York Bight. Results of the quantitative analyses may be used to evaluate plumes, their dispersion characteristics, and environmental effects.

2. EXPERIMENTS

Remotely sensed data were collected in conjunction with sea-truth measurements in three experiments in the New York Bight apex of the Atlantic coastal zone, figure 1. Sea truth measurements were made by the National Oceanic and Atmospheric Administration (NOAA) in these joint experiments. Pollution features of primary interest in these experiments were ocean dumped materials, such as sewage sludge and acid waste. In the first experiment in April, 1975, acid waste and sewage sludge plumes were evaluated. In the second experiment on September 22, 1975, plumes resulting from dumping of sewage sludge by two methods were analyzed. The first dumping method is a "line" dump in which the sewage sludge is dispersed over a 3 to 4 kilometer (km) track from a moving barge in a 30 to 45 minute period. The second dumping method is a "spot" dump

in which the sewage sludge is discharged in one location in about 5 minutes. In the third experiment on July 15, 1976, remotely sensed data were collected during multiple passes over a sewage sludge spot dump to study temporal dispersion characteristics. In addition, in this third experiment, spectral data were collected over an "unknown" sewage sludge dump and an in-progress acid waste dump.

Two National Aeronautics and Space Administration (NASA) multispectral scanners were used in the experiments reported here. The first scanner, which was flown in April, 1975, is the Ocean Color Scanner (OCS) onboard a NASA Ames Research Center (ARC) U-2 aircraft from an altitude of 19.7 kilometers (km) (65,000 ft). Spectral and spatial characteristics of the OCS are listed in table I. Experiment operations are described in reference 10. The second scanner, a Modular Multispectral Scanner (M2S), was flown on the September 22, 1975, and July 15, 1976, experiments onboard a NASA Johnson Space Center (JSC) P-3A aircraft. Spectral and spatial characteristics of the M2S and the mapping camera for the 3.0 km (10,000 ft) flight altitude are shown in table II. Operations for the September 22, 1975, experiment are described in reference 11.

3. DATA ANALYSIS

Qualitative Analysis

Qualitative analysis of pollution features includes location, identification, and mapping their extent. In general, pollution features have radiance levels different from those of the background water in one or more spectral regions. In almost all cases, plumes in the coastal zone have higher radiances (than the background water) that are due to suspended materials in the plumes (e.g., refs. 3, 4). These differences have been observed in photographic and digital remotely sensed data. Identification of pollution features without concurrent sea-truth measurements requires consideration of atmospheric as well as pollutant spectral responses. One method of "normalizing" environmental effects (e.g., atmospheric and Sun angle) between scenes is to use an in-scene calibration. The approach used in the results reported here was to determine ratios of plume radiances to background (ocean) water for the same remotely sensed scene in each of the multispectral scanner bands. These ratio values as a function of wavelength indicate unique characteristics that may be used for identification of plumes resulting from ocean dumping of acid waste and sewage sludge. After the plumes have been located and identified, they may be mapped using radiance differences in one (density slicing techniques) or more (classification techniques) spectral bands.

Quantitative Analysis

The quantitative analysis used is based on previously developed multiple regression techniques (refs. 7, 8, and 9). Specifically, a stepwise regression analysis is applied in which only statistically significant spectral bands are included in regression equations that relate remotely sensed data to parameters in the water column. These calibrated regression equations have been used to map distributions of water quality parameters, such as suspended sediment and chlorophyll a (refs. 8, 9).

4. RESULTS

Qualitative Analysis

Qualitative analysis of remotely sensed data includes location, mapping, and identification of features without the requirement for concurrent sea-truth measurements. Photographic and scanner radiance measurements from the September 22, 1975, experiment will be used to demonstrate how remotely sensed data have been analyzed. Spectral data will then be compared from the April 1975 and July 1976 experiments to demonstrate that the in-scene calibration technique provides a means for identification of acid waste and sewage sludge plumes over a range of experimental conditions.

Photographic results showing plumes from two sewage sludge dumps are shown in figure 2 (taken from ref. 11). The photograph was taken by a Zeiss mapping camera from 3.0 km (10,000 ft) at 11:59 a.m. eastern daylight time (e.d.t.), about 1 hour after the dumps. As noted in figure 2 the line dump took place from 10:46 a.m. to 11:16 a.m. and the spot dump from 11 a.m. to 11:05 a.m. The spectral image of the plumes, shown in figure 3, was obtained by mapping contours at different radiance levels in M2S Band 9 (760-860 nanometers (nm)). The essential outline of the plume is adequately represented by either figure. Spectral responses using the in-scene calibration technique over the visible and near IR spectral ranges for the two plumes are shown in figure 4. Also shown are spectral responses for the two plumes about 5 hours after dumping, indicating lower radiance values with dispersion of the plume over time, as expected. Also note that these are no large spectral shifts with time.

Location of pollution features and their mapping by density slicing and/or classification techniques is well developed (e.g., refs. 2, 3, 4, and 6). Thus, only results related to identification of pollution features will be presented for the April 1975 and July 1976 experiments. Spectral responses for acid waste and sewage sludge plumes obtained on April 9 and 13, 1975, are shown in figure 5. Recall these data were obtained by the OCS at a flight altitude of 19.7 km.

Spectral responses from sewage sludge and acid waste dump plumes on July 15, 1976, are shown in figure 6. In this figure, three curves are shown for sewage sludge plumes, the fourth curve is for an acid waste dump. The multispectral scanner was the M2S flown at an altitude of 3.0 km (see table II).

Note the general similarity of sewage sludge response curves (figs. 5 and 6) with peak ratio values occurring at wavelengths of about 700 to 800 nm. On the other hand, the peaks for the acid waste plumes (figs. 5 and 6) occur at about 600 nm. Thus, the curves of figure 6 appear qualitatively typical of spectral responses for sewage sludge and acid waste plumes over a range of experimental conditions.

Quantitative Analysis

Quantitative distributions of suspended solids in sewage sludge dumps were determined in an experiment in the New York Bight on September 22, 1975, involving two methods of dumping sewage sludge. The multiple regression (e.g., step-wise regression) analysis techniques were used to analyze M2S data that had been collected concurrently with sea-truth measurements by NOAA and the State University of New York (SUNY). In this particular experiment, only five of the ten possible M2S bands provided useable data; however, the bands available (2, 3, 4, 7, and 9) appear to give adequate spectral coverage.

Ten surface water samples were taken within 20 minutes of the aircraft over-pass. Five of the samples were taken in the line dump plume and five taken in water adjacent to the plume. Measured values of suspended solids and chlorophyll a along with radiance values at the corresponding locations are listed in table III.

Suspended solids and chlorophyll a concentrations were analyzed quantitatively with remotely sensed data (see ref. 9 for a detailed description of the procedure used). The calibrated regression equation used radiance changes in M2S bands 4 and 9 for determining suspended solids concentration changes; however, there were no significant radiance changes with chlorophyll a concentration changes. The linear regression equation for suspended solids had a correlation coefficient of 0.961 and a standard error of estimate of 4.11 mg/l over the measured range from 1.11 to 32.2 mg/l. Comparison of the estimated suspended solids, calculated from the linear regression equation, and measured values are shown in figure 7. Prior investigations (refs. 7 and 8) have indicated linear responses for suspended solids in this range of measurements.

Applying the suspended solids regression equation to radiance data in the remotely sensed scene, quantitative distributions of suspended solids were determined and a map developed using a computerized contour routine.

Quantitative distributions of suspended solids in the sewage sludge dumps are shown in figure 8. The sea-truth measurements in the spot dump were not included in the regression equation; however, estimated values of 14-18 mg/l, from the linear multiple regression equation, compare favorably with the interpolated measured value of 12 mg/l obtained in the spot dump.

5. CONCLUDING REMARKS

Results of field experiments conducted in the Atlantic Coastal Zone indicated that pollution features such as plumes resulting from ocean dumping of sewage sludge and acid waste, have unique spectral characteristics. These spectral characteristics indicate significant differences over a range of experimental conditions when an in-scene calibration technique is used. In this technique the radiance ratio of the pollution feature (i.e., sewage sludge or acid waste plume) to ocean water is determined. The resulting uniquely shaped curve as a function of wavelength may be used to identify the pollution feature. After identification, the extent of the pollution feature is mapped based on radiance differences between the plume and the background water. This approach may be used to locate, identify, and map their distributions, without concurrent sea truth. This technology base may be used for the development of a remote sensing monitoring system; for example, to monitor ocean dumping in the New York Bight.

Quantitative analysis approaches may be used when concurrent sea-truth measurements are made. Results of these analyses, calibrated regression equations, have been used to determine quantitative distributions of water quality parameters, such as suspended solids in plumes resulting from sewage sludge dumps. These numerical results provide information for determining dispersion coefficients and environmental effects. Sea truth measurements in the September 22, 1975, sewage sludge monitoring experiment included chlorophyll a; however, there was no statistically significant correlation between changes in chlorophyll a concentrations and radiance values.

Results of experiments to date indicate that primary features such as acid waste and sewage sludge plumes may be distinguished by multispectral analysis techniques. In addition, changes in suspended solids concentrations in sewage sludge plumes produce spectral variations that may be used to develop calibrated regression equations. This procedure may then be applied to extend sea-truth measurements at a limited number of stations to map distributions of suspended solids in the remotely sensed scene. Additional factors to be evaluated in future tests, include dumping and mixing rates, type of sewage sludge treatment, and composition of the material (e.g., acid wastes) being dumped. In addition, further studies and measurements of receiving waters will aid in interpretation of factors such as the application of in-scene calibration techniques.

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SPECTRAL 423 - 782 NANOMETERS (nm)		
RANGE	BAND	RANGE
BANDS		
	1	433 nm ± 10 nm
	2	471 nm ± 10 nm
	3	509 nm ± 10 nm
	4	547 nm ± 10 nm
	5	583 nm ± 10 nm
	6	620 nm ± 10 nm
	7	662 nm ± 10 nm
	8	698 nm ± 10 nm
	9*	733 nm ± 10 nm
	10*	772 nm ± 10 nm

*BANDS NOT IN ANALYSIS

STATION	SEA TRUTH		REMOTELY SENSED RADIANCES, mw/cm ² - ster - μm				
	SUSPENDED SOLIDS mg/l	CHLOROPHYLL a mg/m ³	M2S BAND				
			2	3	4	7	9
1	1.53	1.0	3.00	3.07	2.92	0.93	0.37
2	1.26	1.0	2.90	2.85	2.01	0.78	0.32
3	27.00	1.5	3.02	2.95	2.06	1.07	0.48
4	1.60	1.2	2.60	2.99	2.15	0.86	0.34
5	30.10	1.9	2.99	2.89	2.00	1.02	0.46
6	1.70	1.1	2.95	2.98	2.15	0.87	0.33
7	32.20	1.8	3.11	3.09	2.19	1.17	0.54
8	1.11	1.2	3.14	3.15	2.25	0.96	0.40
9	13.26	1.5	3.27	3.26	2.28	1.21	0.50
10	13.36	1.5	3.28	3.27	2.30	1.04	0.41
SPOT*	12.0**	--	3.30	3.45	2.51	1.36	0.52

* AVERAGE NEAR SUNY SHIP ONRUST

** INTERPOLATED VALUE

SPATIAL	
FIELD OF VIEW	
WIDTH, M	25 000
LENGTH, M	CONTINUOUS
RESOLUTION, M	75

TABLE III. SEA TRUTH MEASUREMENTS AND
REMOTELY SENSED DATA IN SEWAGE SLUDGE
PLUME ON SEPTEMBER 22, 1975.

TABLE I. OCEAN COLOR SCANNER SPECTRAL
AND SPATIAL CHARACTERISTICS AT 19.7
KILOMETERS (65,000 FT) ALTITUDE.

I MODULAR MULTISPECTRAL SCANNER (M2S)		
RANGE	380 - 1060 nm + THERMAL	
BANDS	BAND	RANGE
	1	380 - 440 nm
	2	440 - 490 nm
	3	495 - 535 nm
	4	540 - 580 nm
	5	580 - 620 nm
	6	620 - 660 nm
	7	660 - 700 nm
	8	700 - 740 nm
	9	760 - 860 nm
	10	970 - 1060 nm
	THERMAL	8000 - 13 000 nm

SPATIAL	
FIELD OF VIEW	
WIDTH, M	8500
LENGTH, M	CONTINUOUS
RESOLUTION, M	9

II ZEISS MAPPING CAMERA			
SPECTRAL RANGE	FILM	RESOLUTION, M	FOOT PRINT, M
300 - 700 nm	2402 (B & W)	1.3	4550 × 4550

TABLE II. SPECTRAL AND SPATIAL CHARAC-
TERISTICS OF REMOTE SENSORS (AT
3.0 KILOMETER ALTITUDE)

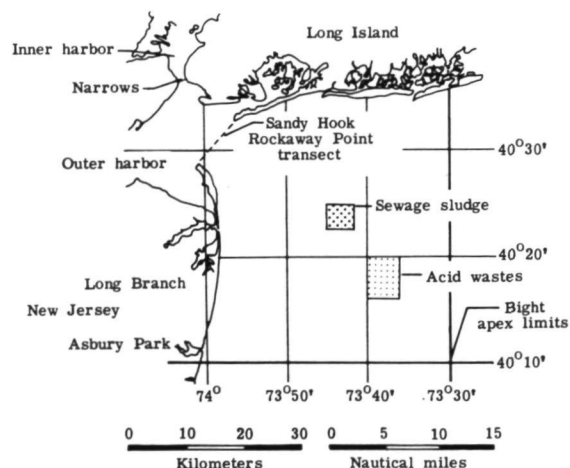


FIGURE 1. OCEAN DUMPSITES FOR SEWAGE
SLUDGE AND ACID WASTES IN THE
NEW YORK APEX.

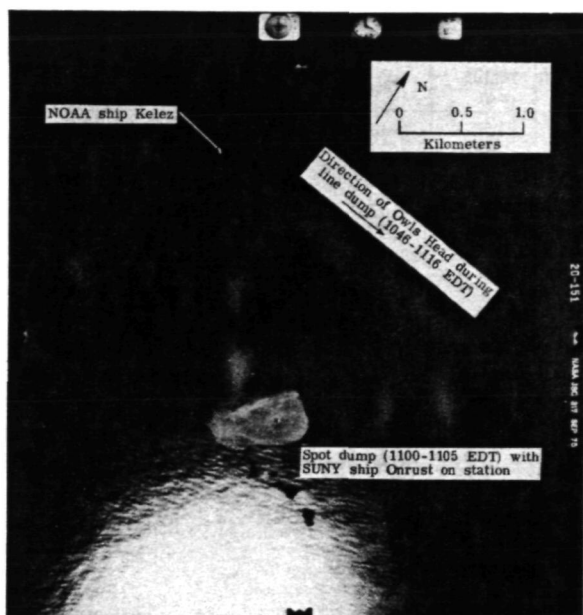


FIGURE 2. AERIAL PHOTOGRAPH AT 1159 EDT SHOWING LINE AND SPOT SEWAGE SLUDGE DUMP PLUMES ON SEPTEMBER 22, 1975.



FIGURE 3. QUALITATIVE MAPPING OF SEWAGE SLUDGE PLUMES OBTAINED BY "DENSITY SLICING" M2S BAND 9, SEPTEMBER 22, 1975.

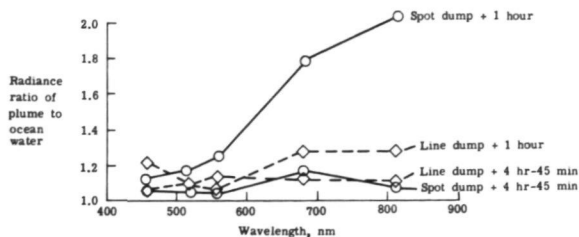


FIGURE 4. RADIANCE RATIOS OF PLUMES FROM LINE AND SPOT DUMPS OF SEWAGE SLUDGE ON SEPTEMBER 22, 1975.

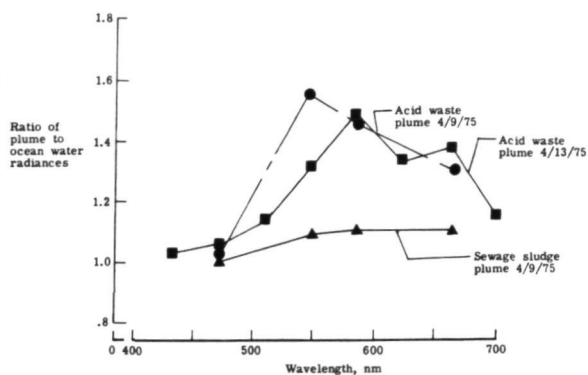


FIGURE 5. RADIANCE RATIOS OF ACID WASTE AND SEWAGE SLUDGE PLUMES ON APRIL 9 AND 13, 1975.

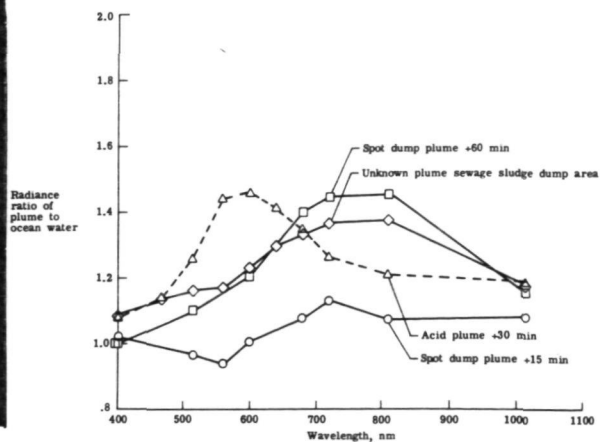


FIGURE 6. RADIANCE RATIOS OF ACID WASTE AND SEWAGE SLUDGE PLUMES ON JULY 15, 1976.

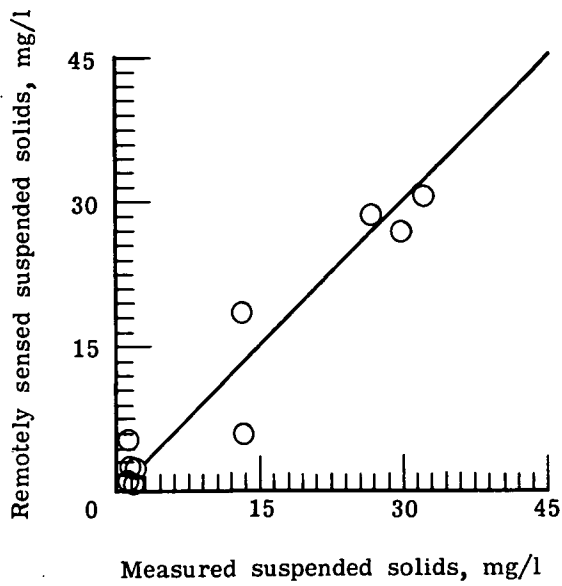


FIGURE 7. REMOTELY SENSED AND MEASURED VALUES OF SUSPENDED SOLIDS IN THE LINE DUMP PLUME ON SEPTEMBER 22, 1975.

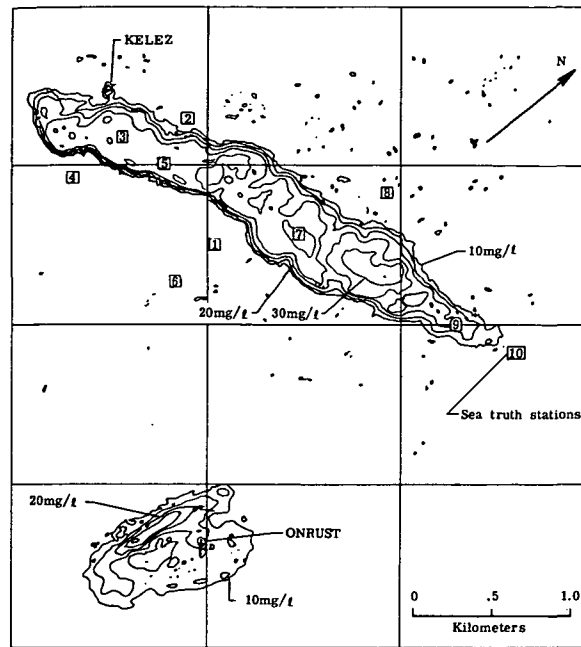


FIGURE 8. QUANTITATIVE DISTRIBUTIONS OF SUSPENDED SOLIDS IN THE LINE AND SPOT DUMP PLUMES ON SEPTEMBER 22, 1975

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DETECTION, IDENTIFICATION, AND QUANTIFICATIONTECHNIQUES FOR SPILLS OF HAZARDOUS CHEMICALS

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ABSTRACT

In this study, we have evaluated the first 400 chemicals listed in the Coast Guard's Chemical Hazards Response Information System (CHRIS) handbook with respect to their detectability, identifiability, and quantifiability by 12 generalized remote and in situ sensing techniques and some of the pollution sensing instruments that are currently available or which could reasonably be expected to be available within the next few years. We have also attempted to identify some of the key areas in the technology of water pollution sensing in which additional research and development efforts are needed.

1. INTRODUCTION

The ARGO MERCHANT oil spill and the contamination of the James River by kepone are recent examples of spills of hazardous chemicals into the waterways of the United States. The possibility of water pollution by chemical spills is a continuing problem in our industrial society, and it is likely, with continued growth in petroleum, chemical, and related industries, that the problem will escalate. The Coast Guard and the Environmental Protection Agency (EPA) have been charged by Congress with responsibilities for monitoring pollution in U. S. waterways. Therefore, they require technological capabilities for quickly detecting, identifying and quantifying spills of hazardous chemicals to minimize the impact upon the environment. This study, supported jointly by the Coast Guard and the EPA, was intended to provide some of the initial technical data that is required by those agencies in meeting their responsibilities for pollution monitoring and control.

The problem of detecting, identifying, and quantifying spilled chemicals in large bodies of water such as rivers, lakes, and the oceans is enormously complex. This is due in part to the large number of chemicals that can potentially be spilled, and to the large diversity of the properties exhibited by those chemicals in water. It is also due to environmental factors such as the turbidity, turbulence, and roughness of the water, background pollutant concentration, and atmospheric conditions.

In recent years, rapid and significant advances have been made in the technology of remote sensing. Little more than a decade ago, the state-of-the-art in remote sensing was largely represented by the techniques of aerial photography. Although photographic techniques can be highly effective in certain applications, their range of effectiveness is limited by the relatively narrow spectral range of available films and by the difficulty of quantitatively analyzing photographic imagery. The development of the optical-mechanical scanner was an important step in remote sensing because it provided a means for quantitative data recording via magnetic tape as well as providing a wide-band multispectral capability. More recently, the availability of lasers, photon counters, optical multichannel analyzers and other advanced electro-optical devices have made possible further significant advances in remote sensing capabilities.

Nevertheless, no remote sensing technique or instrumentation system for unattended in situ pollution monitoring is yet available that can adequately detect, identify, or quantify a broad range of chemicals under normal environmental conditions. It is generally recognized that a multisensor approach is required to achieve a reasonably effective operational pollution monitoring

capability. The Coast Guard's AOSS (Airborne Oil Spill Surveillance) system, utilizing radar, passive microwave, thermal infrared, and video (TV) sensors, is an example of a system of this type.

Numerous factors will affect the detectability, identifiability, and quantifiability of a given spilled chemical. The nature and degree of influence of these factors will depend on the type of instrumentation system used. A list of important factors would include:

- type of sensing system - remote or in situ;
- distance from the sensor to the water;
- zenith angle of the observation;
- system sensitivity;
- distance from the source of the spill;
- time since the spill;
- concentration of the chemical;
- turbidity of the water;
- turbulence and surface roughness of the water;
- salinity of the water;
- water depth;
- density of biological organisms;
- background pollutant concentration;
- weather conditions; and
- ambient lighting.

It was not the intent of this study, nor is it feasible, to perform an analysis which takes into account all of these factors. The ways that they individually and in combinations affect remote and in situ sensing measurements could constitute numerous profitable research topics.

In this study, we have evaluated the first 400 chemicals listed in the Coast Guard's Chemical Hazards Response Information System (CHRIS) handbook with respect to their detectability, identifiability, and quantifiability by some of the pollution sensing instruments that are currently available or which could reasonably be expected to be available within the next few years. We have also attempted to identify some of the key areas in the technology of water pollution sensing in which additional research and development efforts are needed.

2. METHOD

Our analysis approach utilized generalized sensing system characteristics and the gross physical, chemical, and optical properties of the CHRIS chemicals to sort out the chemicals that are likely to be detectable, identifiable, and quantifiable by each of the twelve sensing methods. This approach yields an estimate of the relative potential detectability, identifiability, and quantifiability of each of the CHRIS chemicals for the twelve sensing techniques. It also yields an estimated, relative, broad-spectrum effectiveness ranking for each of the sensing techniques. Without precisely defining acceptable ranges for environmental conditions, we assumed that a favorable set of environmental conditions exists for each sensing system.

To conduct this study, it was necessary to identify, from a long list of analytical and remote sensing techniques, those techniques which could be both practical and effective in field applications to detect, identify, and quantify chemical spills in water bodies. Appropriate techniques should have several attributes, including the capability of detecting a broad range of chemicals, reliability, stability, capability for unattended or automatic operation, and low power requirements. For in situ sensing systems, an important consideration is that no sample preparation should be required. The following techniques were selected:

1. Optical reflectance;
2. Thermal infrared (passive sensors);
3. Passive microwave;
4. Radar;
5. Fluorescence;
6. Raman scattering;
7. Ion-selective electrodes;
8. Electroconductivity;
9. Reduction-oxidation potential;
10. Optical absorptimetry;
11. Dissolved oxygen;
12. Total oxygen demand.

These systems can be categorized as either "in situ" or "remote" sensing systems. In this study, in situ systems are those which operate in direct contact with the water, and remote systems are those which operate at some distance from the water. Using these definitions, the first six techniques in the above list are primarily applicable to remote sensing. Fluorescence and Raman scattering techniques can also be implemented effectively for in situ applications. The last six techniques are limited to in situ applications.

The ability of a sensor to detect, identify, or quantify a chemical depends largely on the accessibility of the chemical to the sensor. For example, a floating chemical is accessible to a thermal infrared detection system, but a sinking chemical is not. The chemical properties which primarily determine accessibility are:

- Solubility in water;
- Density;
- Vapor pressure;
- Reactivity;

Recognizing that highly volatile or reactive substances constitute a special problem, it was sufficient in this study to focus primarily on the properties of solubility and density. On this basis, each chemical can be assigned to one of four accessibility groups:

<u>Accessibility Group</u>	<u>Floats</u>	<u>Soluble</u>
1	yes	yes
2	yes	no
3	no	yes
4	no	no

Numerical accessibility values were assigned to each accessibility group/sensing system combination. The lower limit on solubility was assumed to be one part per hundred.

The second basic consideration in this analysis is that in order to be detected, identified, or quantified by a given sensing system, a spilled chemical must possess specific optical or electrochemical characteristics. Each chemical was evaluated with respect to those characteristics, and numerical system applicability values were assigned to each chemical/sensing system combination. In many cases, the available data were insufficient. This problem was handled by considering molecular structures, possible ionic strengths, ion mobility, stability under environmental conditions, viscosity, etc. For example, chemical structure is of prime importance in determining the strength of fluorescence.

3. RESULTS

The numerical accessibility factors and system applicability factors were combined by digital computer for the 14,400 possible chemical/sensing system/sensing function combinations. The results were displayed in the form of charts or numerical matrices. The numerical analysis yielded:

- 1) The estimated relative, potential effectiveness of each of the 12 generalized sensing techniques for detecting, identifying, and quantifying each of the 400 CHRIS chemicals.
- 2) A numerical estimate of the overall relative, potential detectability, identifiability, and quantifiability of each of the 400 CHRIS chemicals.
- 3) A ranking of the relative effectiveness of each of the 12 generalized sensing techniques for detecting, identifying, and quantifying all 400 CHRIS chemicals.

Because of space limitations these results can only be summarized in a general way here. Figure 1 is a chart which lists the numbers of chemicals from the CHRIS list that are estimated to be potentially detectable, identifiable, and quantifiable by the 12 generalized sensing systems. Also shown in Figure 1 are the corresponding numbers for currently available water pollution sensing instrumentation. These results were derived by using available product information which was not necessarily complete. Nevertheless, these results probably do provide a reasonable estimate of current capabilities. It is vital to realize, however, that in many cases a sensor can only detect, identify, or quantify a given chemical under special circumstances. For example, most of the chemicals listed as detectable by optical reflectance methods are detectable by a specific instrument which is useful but which, nevertheless, has a small field of view and operates at relatively short range.

The analysis indicates that 253 of the 400 CHRIS substances can be detected by at least one available pollution sensor under certain operational and environmental conditions. The identification and quantification capabilities of existing remote and in situ sensing systems appear to be minimal.

4. CONCLUSIONS AND RECOMMENDATIONS

It should be stressed that broad-spectrum pollution monitoring is a complicated matter, involving many environmental factors as well as the characteristics and limitations of available instrumentation. It is clear that it is impractical if not impossible to cope with every environmental variation, to put a sensor at every location where pollution is possible, to survey every square mile of water surface or to detect every chemical that is spilled. Studies should, therefore, be made to determine and evaluate the relative probabilities for spillage of each of the CHRIS chemicals, probable spill mechanisms and locations, and areas of probable greatest hazard to the environment and to human health. Theoretical and experimental programs should be initiated and supported to study pollution transport and dispersal mechanisms in crucial areas such as rivers, harbors, and coastal zones. Both generalized and site-specific transport models should be developed for the purpose of predicting the spatial and temporal distributions of chemicals having a wide range of chemical characteristics in water

The optimum design and deployment of pollution sensors as well as effective planning for the control and cleanup of possible chemical spills will require the completion of research programs of this kind.

This study supports the generalization that identification and quantification of chemical spills will be more difficult and costly than the already difficult task of detection alone. Therefore, assuming that funding for the development, deployment, and maintenance of pollution sensing equipment will not be unlimited, it would be useful to consider how much effort should be expended, in the short term, on the development of each of these desired capabilities.

Under certain circumstances, mainly where fixed sensors can be employed, it will not be too difficult to achieve a limited spill identification capability. Several methods are possible. Some, such as Raman scattering and IR reflectance measurements have been included in this study. Others, such as measurements of optical scattering and absorption spectra in the vapor emitted by the chemical, gas chromatography, and multisensor approaches, can be developed. But to develop and implement a comprehensive capability, geared to a wide range of chemicals and operable under a wide range of environmental conditions and spill locations, would require a massive, costly effort. Specific and reasonable needs for identification capabilities should be defined in order to maximize the cost effectiveness of hardware development programs. For the same reasons, the need for quantification capabilities should be similarly considered.

The task of water pollution monitoring requires the surveillance of large areas of oceanic, coastal, and inland waters. For this reason, aerial sensing systems, particularly real-time imaging systems, should receive careful attention and be utilized to the maximum possible extent. Data formats and on-board image display systems should be designed to derive the maximum practicable benefit from the processing power of state-of-the-art digital electronics as well as the pattern recognition sensitivity of the human eye and mind when viewing two-dimensional imagery. The design of data processing, display, and recording instrumentation will be a major factor in determining the effectiveness of aerial remote sensing systems and should not be underemphasized in development programs.

The following items briefly outline several additional suggestions for developing and implementing pollution sensing techniques.

- Raman measurements promise to provide a chemical identification and quantification capability in many in situ and non-aerial remote sensing applications. Efforts should be directed to finding and implementing methods for increasing the signal levels and signal-to-noise ratios of Raman (and fluorescence) measurements. This would include the development of advanced Raman techniques which will allow the separation of a Raman scattering spectrum from a fluorescence spectrum.
- Instrumentation systems which incorporate several kinds of pollution sensors will have much greater capabilities for chemical detection, identification, and quantification than can be obtained from any single sensor. The effectiveness of combining sensors in this way was not explicitly evaluated in this study but it should be evaluated in future work.
- Digital signal processing capabilities are vital for deriving the maximum possible information from remote and in situ sensors. Useful functions include signal averaging, signature recognition, background subtraction, data display, and control of operational modes.
- Several techniques for detecting and identifying molecules of a pollutant in the air have been described in the literature. These techniques have not been included in this study, but should be evaluated in future work.
- A significant group of chemicals are insoluble and heavier than water (Accessibility Group 4). Detection of these chemicals is difficult and unlikely except by placing sensors on the bottom of the water body at the proper locations. The importance of making the effort to detect

these substances, the kinds of sensors to employ, and the definition and location of key monitoring sites should be determined by further studies.

- Interference effects are a problem for in situ sensing methods, particularly in inland and coastal waters. These effects can be caused by ambient chemical or ion concentrations, suspended solids, and natural organic matter. Filtering can reduce the problem somewhat for some in situ sensors. Built-in microprocessors may provide an additional means for reducing the problem in addition to enhancing real-time, automatic, analytical capabilities.
- Optical absorption spectra in the UV-visible spectral region are not available for most of the CHRIS chemicals. These spectra should be measured.
- Thermal IR and microwave emissivity values are not available for most of the CHRIS chemicals. These quantities should be measured in order to implement IR and passive microwave sensing methods effectively.

The potential applicability and effectiveness of twelve generalized remote and in situ sensing techniques have been estimated in this study. But those estimates are only an initial step in what should be a sustained program to evaluate and develop pollution sensing techniques and instrumentation. Field experiments and measurements involving a broad spectrum of chemicals and a wide range of environmental factors are needed together with laboratory measurements that are directly relatable to field measurements. Numerous field and laboratory experiments have been conducted to study the detectability of oil spills, yet the body of knowledge gained from those studies is by no means complete or definitive. The scope of the research needed to deal with a broad range of chemicals will be appreciated if it is realized that oils are among the easiest chemicals to detect.

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SYSTEM	POTENTIAL			CURRENT		
	DETECTABLE	IDENTIFIABLE	QUANTIFIABLE	DETECTABLE	IDENTIFIABLE	QUANTIFIABLE
OPTICAL REFLECTANCE	133	9	0	133	0	0
THERMAL INFRARED	56	0	0	56	0	0
PASSIVE MICROWAVE	48	0	0	40	0	0
RADAR	79	0	0	47	0	0
FLUORESCENCE	40	0	36	40	0	36
RAMAN SCATTERING	69	69	69	0	0	0
ION-SELECTIVE ELECTRODES	50	0	12	50	0	12
ELECTROCONDUCTIVITY	48	0	0	48	0	0
REDUCTION-OXIDATION POTENTIAL	40	0	0	40	0	0
OPTICAL ABSORPTIMETRY	28	0	28	28	0	28
DISSOLVED OXYGEN	47	0	0	47	0	0
TOTAL OXYGEN DEMAND	37	0	0	37	0	0

FIGURE 1. ANALYSIS SUMMARY. Number of CHRIS chemicals estimated to be potentially and currently detectable, identifiable, and quantifiable by each of the 12 generalized sensing techniques.

INTRALAB'S MISSION IN APPLICATIONS TRANSFER

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ABSTRACT

The Information Transfer Laboratory (Intralab) at NASA/Goddard Space Flight Center is designed to promote the operational use of satellite remote sensing systems. Intralab, in partnership with key potential users (both public agencies and private industry), undertakes projects to help these users discover how to apply remotely sensed data to meet their operational information needs. Intralab's approach to these projects requires intimate user participation, from project definition through final documentation, and emphasizes the processes that the user should adopt to successfully integrate remote sensing into his routine operations. Intralab's earth resources specialists (geographers, foresters, etc.) have access to a full complement of contemporary processing and analysis equipment, ranging from simple photointerpretation instruments to high performance digital processing systems. Thus our goal is to provide the environment for a thorough testing and evaluation of satellite technology, in order that participating users can become sustaining and independent users of that technology.

The poster presentation summarizes the components of Intralab's technology transfer program with specific reference to past and current projects. Landsat applications are examined in various operational settings: private industry (Weyerhaeuser Company and Rochester and Pittsburgh Coal Company), local government (San Jose City Planning Department and the Baltimore Regional Planning Council), and federal agencies (U.S. Bureau of the Census and the Appalachian Regional Commission). Technical applications include forest inventory, lineament analysis, and regional land cover mapping for a variety of specific objectives. Approaches tested for these applications range from photointerpretation of standard Landsat photographs through interpretation of computer enhanced imagery to digital processing of CCT data via remote job entry or video interactive image analysis computer systems. The emphasis in these projects is not merely on technical success, but on the processes by which success is achieved as well. While institutional arrangements differ, these users nevertheless share common concerns and goals. What operational information does Landsat provide, at what cost, and can the user realize benefits that outweigh the costs?

frp,

To address these issues properly, we must remember that "technology transfer" embodies two concepts. Technology can be demonstrated in the laboratory, e.g., in a pilot project. But transfer doesn't occur in the laboratory - it occurs in the user's place of business. And it occurs not merely because the technology exists, but especially when the potential user is able to discover for himself the opportunities to apply that technology to meet his information needs. Technology transfer is not simply a demonstration or pilot project after which one (often vaguely) expects the user to "buy" the technology. It is, rather, a complex mixture of need and opportunity.

The need is partially a desire by the user for more and better information; the Landsat system can often satisfy this aspect. But the need cannot be fulfilled until the Landsat information can be integrated with other information already available to the user. This means the potential user must, if he is to decide to adopt a new information source, have the

opportunity to examine the institutional constraints and advantages. He must appreciate the reliability of the data, and the dependability of its source. He must also know that he has the resources - facilities, manpower, dollars - with which to extract and utilize the information. He must understand how such information contributes to his decision processes. Given the almost infinite variety of institutional situations, it is fatally presumptuous of a technology transfer agent to believe he knows the answers to these questions. It is enough that he knows such questions exist, and is willing to create or contribute to an environment in which these questions can be answered.

U.S. COAST GUARD AIRBORNE OIL SURVEILLANCE SYSTEMS

STATUS REPORT

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SUMMARY

The U. S. Coast Guard, through the provisions of legislation such as the Federal Water Pollution Control Act and the Marine Sanctuaries Act, is assigned the responsibility of enforcing anti-pollution discharge laws and regulations in the navigable waters of the United States. To meet this responsibility, the Coast Guard has embarked on a program to equip a number of new Medium Range Surveillance (MRS) aircraft with operational sensor systems designed to detect, quantify, identify, map and document oil spills on the open ocean. A major step in that program was the development of the Airborne Oil Surveillance System (AOSS).

The prototype AOSS was developed by Aerojet ElectroSystems Company for the Coast Guard through a program initiated in 1972. The AOSS was designed to be a real-time all weather, day-night sensor system with the capability to (1) detect oil slicks, (2) indicate the magnitude of spills - areal extent and approximate thickness, (3) identify and document the source(s) of discharge, (4) assess cleanup operations, and (5) gather data regarding the frequency and magnitude of significant spills.

The prototype system was installed aboard a Coast Guard HU-16E Albatross and flight-tested off the California coast. Controlled testing of the system was completed in October 1974. During 1975 the prototype AOSS aircraft was used operationally by the Coast Guard to evaluate the system effectiveness in detection; monitoring and assessment of offshore oil discharges; search and rescue operations; ice reconnaissance missions; and monitoring of foreign fishing activities in coastal waters. Approximately 350 hours of operational experience were realized.

The results of both the controlled testing and operational evaluation prompted a decision by the Coast Guard to incorporate several improvements to the system and transfer the improved version to an operational C-130 as a permanent installation.

The operational version of the AOSS is an integrated multisensor system configured to provide effective airborne oil surveillance over a wide range of operating conditions. The system uses a sidelooking radar system and a passive microwave imager for long range ship-spill surveillance up to 25 miles from each side of the aircraft. This combination permits effective detection and oil slick mapping day or night and under all but extreme weather conditions. The system also includes an aerial reconnaissance camera and multichannel line scanner for high resolution documentation of oily discharges and suspected violators. This total sensor combination permits multispectral false target discrimination and an approximation of the magnitude (area and thickness) of slicks.

The sidelooking radar system is a modified APS-94D system which uses a unique 8-foot, vertically polarized antenna for oil detection and mapping. A standard 16-foot horizontally polarized antenna complements the 8-foot antenna to provide a 50 nautical mile swath width. This system produces a near real-time radar map on film. The 37 GHz passive microwave

imager is horizontally polarized and scans in a conic arc with a constant incidence angle of 45° . The dual-beam imager has internal calibration sources and is Dicke-switched. The RS-18MS multispectral line scanner operates in three bands: 8 to 14 micrometers, 8.0 to 9.5 micrometers and 0.32 to 0.38 micrometers. The camera is a standard KS-72 aerial reconnaissance camera.

The four sensors and a position reference system are integrated by means of a software-controlled operator console with real-time video displays. This arrangement permits the operator to select the best sensor(s) for the prevailing conditions so that the unique advantages of each sensor can be used and their individual limitations avoided. All imagery is automatically annotated using an airborne data annotation system interfaced with the computer console. Sensor data from any of the sensors can be converted to a common display format by the processing display subsystem to facilitate operator interpretation of the data. Data displayed can also be recorded on a video tape recorder.

The AOSS/C-130 system is undergoing flight testing at the present time and will be operational during April 1977.

PASSIVE MICROWAVE REMOTE SENSING OF SOIL MOISTURE

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Abstract

The paper summarizes the work accomplished in the Voyeykov Main Geophysical Observatory on passive microwave remote sensing of soil moisture. The theory and calculations of microwave emission from the medium with the depth-dependent physical properties are discussed; the possibility of determining the vertical profiles of temperature and humidity is considered; laboratory and aircraft measurements of the soil moisture are described; the technique for determining the productive-moisture content in soil, and the results of aircraft measurements are given.

1. Introduction

The determination of the state of the soil and especially of the soil moisture is one of the important applications of passive microwave remote sensing. The solution of such a problem is possible because of the strong dependence of soil microwave properties on moisture caused in its turn by humidity-dependent dielectric constants of soil.

Beginning from 1969, such studies are being performed in the Main Geophysical Observatory. Laboratory, field and aircraft measurements of microwave emission were made along with theoretical studies and model calculations. These studies were originally associated with remote sensing of soil temperature and moisture, the determination of their vertical profiles included. Then the main efforts were made in assessment of soil moisture and the productive-moisture content in soil, which was most important from the practical point of view.

2. The Theory of Microwave Emission from the Vertically-Inhomogeneous Medium

Actual objects emitting in microwave wavelength region are the solid non-magnetic media with continuously varying properties. The emission from such media is calculated with the phenomenological radiation-transfer equation, which is the equation of the energy balance for a medium [1]. The applicability of such a technique to calculations of microwave emission from an actual underlying surface (soil, in particular), the electrical characteristics of which can be heavily depth-dependent, is not properly grounded.

The thermal emission is a kind of fluctuations and can be described by the correlation theory for electrodynamical fluctuations of arbitrary quasi-equilibrium microscopic systems. The thermal emission theory is well-founded by A. Stogryn [2].

Calculations of the thermal emission by the numerical method of A. Stogryn are rather complicated, but in the case of the media with slowly varying properties they can be significantly simplified and reduced to the form comparable with the transfer equation (3). For the media with a large scale micro-inhomogeneities, for which the condition of

$$\left| \frac{d\varepsilon}{dz} \right| \ll \frac{\omega}{c} \varepsilon \quad (1)$$

is always met, the expression for radiobrightness temperature which corresponds to the thermal emission from an inhomogeneous medium (soil) into vacuum is as follows

$$T_{\delta \vec{p}} = (1 - |R_{\vec{p}}|^2) \int_0^{\infty} T(z) \alpha(z) \cdot S(z) \times \exp \left[- \int_0^z \alpha(z') S(z') dz' \right] \cdot \frac{S(0) \cdot n(z)}{S(z) \cdot n(0)} dz \quad (2)$$

where $R_{\vec{p}}$ is Fresnel coefficients;

ε, n, κ are the dielectrical penetrability, and the indices of refraction and absorption of the medium, respectively;

$\alpha(z) = 2 \frac{\omega}{c} \kappa(z)$ is the absorption coefficient;

ω is the cyclic frequency of emission in vacuum;

c is the light velocity

$$S = \left(\frac{n^2 - \kappa^2 - \sin^2 \theta}{2 \kappa^2} \right)^{1/2} \left[\sqrt{1 + \frac{4 n^2 \kappa^2}{(n^2 - \kappa^2 - \sin^2 \theta)^2}} - 1 \right]^{1/2} \quad (3)$$

θ is the angle of sighting.

The expression obtained can be written as the product of the integral (which determines the emission intensity in the medium near the boundary) and the emissivity of the medium.

Expanding the $S(z)$ and $n(z)$ functions in the integrand of Equation (2) to the accuracy of the first order $S(z) \approx S(0) + S'(0)z$; $n(z) \approx n(0) + n'(0)z$ and using the averaging we obtain

$$T_{\delta \vec{p}} = \Sigma_{\vec{p}} T_e \quad (4)$$

where

$$T_e = \int_0^{\infty} T(z) \alpha(z) S(z) \exp \left[- \int_0^z \alpha(z') S(z') dz' \right] dz \quad (5)$$

is the effective temperature of emission from the medium; $\Sigma_{\vec{p}}$ is the emissivity of the medium

$$\Sigma_{\vec{p}} = (1 - |R_{\vec{p}}|^2) \left[1 - \left(\frac{S'(0)}{S(0)} - \frac{n'(0)}{n(0)} \right) \bar{Z} \right] \quad (6)$$

The result of averaging Z with the function $K(z)$

$$\mathcal{K}(z) = \alpha(z) S(z) \exp \left[- \int_0^z \alpha(z') S(z') dz' \right]$$

having the meaning of probability and meeting the condition of

$$\int_0^\infty \mathcal{K}(z) dz = 1$$

can be used as $\bar{Z}$.

The specific form of Equation (6) is determined by the approximate solution of the wave equation. For the higher accuracy, in Equations (4), (5) should be calculated following the current methods for determination of the inhomogeneous media emissivities. The values of the inhomogeneous media emissivities obtained by solving Rikkati equations will be presented below.

Consider the $S(\theta, Z)$ function. Transform Equations (2), (3) for the case of the relatively weak absorption ($\chi \ll n$).

Then

$$S(z) = \frac{n(z)}{[n^2(z) - \sin^2 \theta]^{1/2}} = \sec \theta'(z) \quad (7)$$

where θ' determines the direction of propagation of the emission in the medium and

$$T_{\vec{p}} = \Sigma_{\vec{p}} \int_0^\infty T(z) \alpha(z) \sec \theta'(z) \exp \left[- \int_0^z \alpha(z') \sec \theta'(z') dz' \right] dz \quad (8)$$

Exp. (8) coincides with solution of the radiation transfer equation. From the point of view of the general theory of electro-dynamical fluctuations of the thermal emission, one can set the limits to the phenomenological theory applicability. The phenomenological theory is totally applicable only for the negligibly absorbing ($\chi \ll n$) weakly inhomogeneous media (see [1]).

Formulae (4)-(6) can be considered as general solution of the transfer equation (8) for the case of arbitrary absorption.

Now, determine the difference between Equation (7) and (8) in the presence of absorption. Figure 1 shows the angular dependences of the $S(\theta)$ and $\sec \theta'$ functions for different values of n and χ . These values of dielectric constants are taken from Reference [4] for the soil with 11% humidity at the wavelength of 0.81 cm. It should be noted that for all the other values of dielectric characteristics of real soil, the difference

between the functions of $S(\theta)$ and $\sec \theta'$ is less than that shown in Figure 1. The difference between the greatest values of $S(\theta)$ and $\sec \theta'$ for $\theta = 90^\circ$ does not exceed 2 percent of the $\sec \theta'$ value.

There is one more fact which reduces the effect of the difference between the $S(\theta)$ and $\sec \theta'$ functions in calculations of radiobrightness temperatures with formulae (4) and (8). For the great values of the absorption index $\mathcal{K}$, with the greatest possible difference between $S(\theta)$ and $\sec \theta'$, the absorption coefficient $\alpha(Z)$ is sufficiently great for the effective emitting layer to be negligibly thin. In this case the radiobrightness temperature is independent of the specific form of the integrand functions. Actually, the calculations of radiobrightness temperatures for the wide range of real temperature profiles and dielectric properties of the medium have shown that the differences in radiobrightness temperatures evaluated with the $S(\theta)$ and $\sec \theta'$ functions do not exceed a few hundredths of a degree.

Thus, the analysis given above shows that in the case of actual emitting media with slowly varying physical characteristics the expression for radiobrightness temperatures obtained on the basis of the theory of electrodynamic fluctuations, coincides practically with a simpler expression used in the phenomenological theory.

Then, one can evaluate the effect of depth-dependent inhomogeneity of the soil on its emissivity. In the microwave region, the dielectrical penetrability of the soil increases with the increase of humidity, and, in some authors' opinion, this dependence is almost linear [5,6]. The humidity, in its turn, varies with depth, this variation being sufficiently diverse. But in a number of cases, humidity can be considered linearly varying with depth throughout the effective emitting layer.

In this case the variation of the dielectric constant coincide with the dependence of humidity on depth. In Ref. [7] we considered the emissivity of the vertically inhomogeneous soil. The reflection coefficient, R , for such a model of soil, closely related to emissivity, was evaluated by solving the Rikatti integral equation with boundary condition of $R \rightarrow 0$ as $z \rightarrow \infty$ given in Ref. [8]. This equation was solved by successive approximation technique, and the result was obtained as a sum of the Fresnel reflection coefficients and the correction which depended on the wavelength, the absolute value and gradient of the soil dielectric penetrability, and the sighting angle. The absolute value of corrections to Fresnel coefficient determined by the vertical inhomogeneity of the soil, increases with the increase of the wavelength, λ , dielectric penetrability gradient, Q , and with the decrease of the boundary value, ϵ_0 . The angular dependences of corrections calculated for $\epsilon_0 = 1.7$;

$\lambda = 60 \text{ cm}$; $Q = 10 \text{ m}^{-1}$ are shown in Figure 2. The corrections for both polarizations are negative and equal for $\theta = 0$. When the sighting angle increases, the absolute value of correction increases for horizontal polarization being the monotonous function of the angle, and decreases for the vertical polarization, reaching the minimum at the angle close to that of Brewster. The analysis of the calculation results has shown that in microwave sensing of the humid soil, the Fresnel formulae can be used to calculate the soil emissivity.

Thus, the theoretical analysis of the electromagnetic waves' propagation through the vertically inhomogeneous soil has shown that in most cases the approximation of the phenomenological theory of radiation transfer is precise enough to evaluate the microwave emission.

3. Remote Sensing of the Physical Parameters of Soil, and its Possibilities

Microwave emission from natural surfaces contains significant information about the physical state of the surface and subsurface layers and can be

applied to remote sensing of natural formations, and a strong dependence of microwave emission on the state of soil contribute to the solution of such a problem. Besides, the absorption coefficients are much smaller throughout the soil thickness in the microwave region as compared to the IR region.

This makes it possible to obtain the information not only about the state of the surface but also about the physical parameters of the soil. In the microwave region, the dielectric constant, ϵ , and the absorption coefficient of the soil, α , increase with the increase of humidity, ω . Humidity and temperature of the soil vary with depth, $T(Z)$ and $\omega(Z)$. Thus, the radiobrightness temperature of the soil, being the functional of $T(Z)$ and $\omega(Z)$, depends on the type of soil and the parameters of the surface state (roughness, the presence and type of vegetation, etc.).

Naturally, a great number of parameters affecting the microwave emission, hampers significantly the indirect sounding of the soil. To determine the radiobrightness temperature sensitivity to variations of different parameters of the soil physical state, a numerical experiment was accomplished [9].

Radiobrightness temperatures were evaluated for sand and clay (which are the extreme types of soil as to their dielectric characteristics) in the wavelength region of 0.8-60 cm, under various physical conditions of their state.

Figure 3 shows the curves of radiobrightness temperatures of the soil with positive and negative temperature lapse rate vs. soil moisture for three wavelengths. At all the wavelengths, the decrease of radiobrightness temperatures is seen to be due to the increase of dielectric penetrability of medium taking place when soil moisture increases and emissivity decreases.

Radiobrightness temperature of the microwave emission from soil varies from 60 up to 90K due to emissivity variations when soil moisture increases from 2 up to 15% depending on the type of soil, wavelength and surface temperature.

The temperature lapse rate affects the radiobrightness temperature for all the humidity values only at the wavelengths greater than 18 cm due to a sufficiently thick emitting layer at these wavelengths. At $\lambda = 3$ cm, the effect of the temperature profile shows only for the absolutely dry soil ($\omega = 2\%$).

For low soil moisture and longer wavelengths ($\lambda \geq 20$ cm), the radiobrightness temperature contrasts can reach 10-20K due to the soil temperature profile variations, i.e., the sign and value of the lapse rate. Radiobrightness temperature dependence on humidity gradient is determined by the value of temperature gradient. However, these variations do not exceed 3K even for great temperature gradients. Such a weak dependence of radiobrightness temperature on humidity gradient testifies the difficulty in indirect evaluation of soil moisture vertical profile from radiobrightness temperature measurements.

In order to increase the humidity gradient contribution to the received signal, we suggest a differential technique for radiobrightness temperature measurements [12]. This technique enables one to eliminate the soil temperature component from the observed data. The calculations made with this technique have shown, however, that the first harmonic of the signal not containing the soil temperature is equal to several degrees, though humidity gradient contribution can reach 50 percent of this value.

Taking account of the fact that the total error due to the uncertainties in radiobrightness temperature measurements and soil characteristics exceeds the first harmonic in Fourier-expansion of the signal, we can say that it is practically impossible to determine the humidity vertical gradient from microwave measurements.

To study the possibilities of temperature and humidity profiles remote sensing, the thickness of the emitting soil layer was evaluated for different wavelengths. For very humid soil ($\omega \sim 20\%$) the emitting layer does not exceed 5 cm even for $\lambda = 18$ cm. The emission from only 10-cm layer reaches the surface at $\lambda = 18$ cm when the soil moisture is 10 percent. And only for the overdry soil (2%) the emitting layer thickness increases up to 20 cm. At the shorter wavelengths, the emitting layer is 2-5 cm.

When analyzing the microwave emission from soil, we have emphasized that the emission from soil is a complex functional of both humidity and temperature, the total effect of temperature and humidity profiles on the emission being observed at all the wavelengths and at all the sighting angles. The impossibility of separating the combined effects of humidity and temperature on the soil emission forces one to confine oneself to indirect evaluation of the temperature profile for a case of soil moisture, which is assumed to be independent on depth [10]. With this assumption made, the inverse problem can be reduced to solution of Fredholm integral equation of the first kind:

$$T(\lambda) = \int_0^{\infty} T(z) K(\lambda, z) dz \quad (9)$$

where $K(\lambda, z) = \alpha \cdot e^{-\alpha z}$ is the kernel of the integral equation (weighting function).

At present, the technique for solving such incorrect (in mathematical sense) problem has been thoroughly developed. In Ref. [10] we used the technique suggested by O. M. Pokrovsky which made it possible to analyze the information content of measurements [11].

Let us consider the characteristic features of the soil microwave emission. Figure 4 shows the kernels of Equation (9) for different soil moistures and two wavelengths. The comparison of these kernels with the similar ones, e.g., in reconstruction of vertical temperature profile of the atmosphere from the outgoing IR emission measurements (Figure 4b) shows that remote sensing of the soil temperature profile is limited. This is due to the following characteristic features of the kernels:

1. At all the wavelengths, the main portion of emission comes from the same surface layers. Thus, the vertical profile reconstruction becomes difficult even at the depth of 10-40 cm depending on soil moisture.
2. The kernels depend heavily on humidity, which verifies the necessity of its independent determination.
3. Due to the strong correlation between the kernels, the solution of the corresponding mathematical problem becomes significantly complicated, and the amount of information about temperature decreases.

The analysis of information content of radiobrightness temperature measurements performed for the kernels calculated for two soil moistures (3 and 12%) and 25 wavelengths over the range of 3-60 cm, has shown that for the measurement errors of 0.5-1K, only one or two independent parameters can be evaluated indirectly. Thus, one cannot expect a detailed information about temperature profile, even in the case of such an idealized inverse problem.

The possibility of solving the inverse problem was evaluated for sand. The program of numerical experiments included the solution of direct problem with Equation (9) as the basis, and of the inverse problem with different errors introduced.

If the measurement errors of radiobrightness temperature measurements is 0.5K, the temperature profile is reconstructed with a good accuracy (1-3K)

under condition of exactly preset humidity and absorption characteristics of the soil. In real conditions, the remote sensing of the soil temperature becomes complicated due to the necessity of highly accurate simultaneous determination of the soil moisture.

Therefore, the conclusion is drawn that only the approximate evaluation of temperature profile is possible on the basis of microwave measurements. It should be pointed out that for complete evaluation of the usefulness of remote sensing technique, a detailed laboratory and field study is necessary to obtain reliable data on physical properties of the soil and to gain the experience in remote sensing of the soil in real conditions.

4. Laboratory Measurements

The Main Geophysical Observatory has developed the technique for experimental determination of emissivities of different underlying surfaces [13] in order to obtain the data on humidity dependence of the soil emissivity. In laboratory conditions, the radiobrightness temperature of the closed cavity with a sample of the soil investigated was measured twice.

First, the emission was measured from the sample illuminated by a heated blackbody mounted above this sample. The second measurement was taken with the absolute reflector placed above. The emissivity of the sampled surface is evaluated from these two independent measurements of the cavity's radiobrightness temperature:

$$\Sigma = 1 - \frac{T_{b1} - T_{b2}}{(\Sigma_{c1}T_{c1} - \Sigma_{c2}T_{c2}) + (1 - \Sigma_{c1})T_{b1} - (1 - \Sigma_{c2})T_{b2}} \quad (10)$$

where T_{b1} , T_{b2} are the radiobrightness temperatures of the cavity measured in the presence of the blackbody or the absolute reflector as the upper surfaces; Σ_c is the emissivity of the upper cover; T_c is its thermodynamical temperature.

For several years, microwave emission from different underlying surfaces was being measured using the above method. Some results were published in Ref. [14]. This paper incorporates the results of laboratory multichannel measurements taken recently in different seasons. Table 1 lists the observed emissivities of different natural surfaces at wavelengths $\lambda = 3.2$ cm and 1.6 cm.

Measurements were made using the improved measuring arrangement with high-temperature blackbody, the emissivity of which was substantially increased, especially at the wavelengths shorter than 3.0 cm.

The emission coefficients were studied for sand and soil with different humidities, frost and thaw soil, the soil covered with snow and without it, the dry and moist grass, peat, clay, hard-surface road, and concrete, dry, moist and covered with snow. Humidity dependence of the soil microwave emission has evoked great interest in connection with the aircraft passive microwave remote sensing of humidity and moisture-content in the soil.

Some aspects of this problem were discussed in Ref. [15]. We measured the dependences of sand and sandy loam emissivities on humidity. Samples 25-30 cm thick were studied. To vary the soil moisture, the surface of the soil was moistened. The soil was sampled by a cutting cylinder both on the surface and at the depth. The soil moisture was determined by weighing, in percentage of moisture weight to that of the dry soil sample. When the soil is moistened, the 25 cm layer acquires a certain humidity profile. But when the soil is heavily moistened, the lower layer can be water-saturated. Figure 5 shows the emissivity of sand and soil vs. humidity at $\lambda = 3.2$ cm. These

data verify the significant decrease of emission from river sand and sandy loam with the increase of surface humidity, which indicates, in its turn, the possibility of remote sensing of the soil moisture. At the same time the measurements have shown that the dependences of sand and soil on humidity are different. For sandy loam sample (the dots in Figure 5), the strongest dependence of emission on humidity shows for humidities greater than 20%. Such a variation of soil emissivity is similar to that of microwave emission from sand and clay at $\lambda = 1.55$ cm, reported in Ref. [16].

Figure 5 shows also the emissivity of sand and clay vs. humidity (curve 1) calculated from dielectric constants taken from Ref. [17]. The theoretical dependence agrees with the observed one (curve 2). However, the observational data show that the dependence of microwave emission from sand on humidity is more prominent and differs significantly from the similar dependence of sandy loam, when it is moistened. Apparently, these differences are associated with the fact that the surface humidity of the soil characterizes inadequately its agrohydrological properties, and the processes of moistening the river sand and sandy loam are different.

Much attention was paid to microwave emission from snow cover, frost soil and unfrozen soil. The sample of soil, the emissivity of which was measured vs. humidity, was preserved in a special bath, and in spring it was frozen. During measurement, the air temperature was $+1.2^{\circ}\text{C}$, the temperature of the sampled surface was -0.4°C , and its emissivity was 0.923 at $\lambda = 3.2$ cm.

After unfreezing, the emissivity of the sample dropped to 0.892. These data correspond to theoretical evidence and show the variation of dielectric constants of water when it freezes.

The data obtained show that the snow cover raises the emissivity of the soil up to 0.956 at $\lambda = 3.2$ cm. Thus, these data testify the possibility of microwave remote sensing of the soil when the snow melts and the soil gradually thaws.

Along with laboratory measurements of the soil samples, the field measurements of microwave emission from soil were taken using the 18-m hinge tower with radio equipment. The results of the field measurements are consistent with the laboratory data. We succeeded in reproducing and studying the daily variations of natural surfaces' emissivities in conditions of sharp temperature contrasts in spring and in the fall, as well as microwave emission variation during freezing and thawing of the soil. The above-mentioned theoretical and experimental studies have made it possible to move on to evaluation of soil moisture from aircraft.

5. Moisture and Water-Content in Soil as Inferred From Aircraft Passive Microwave Remote Sensing

The productive-water content in soil, i.e., the amount of water in the 1-m layer which can be used by plants, has the main influence on crop formation in the regions with insufficient or unstable moisture. The information about water content in soil accumulated in spring by the beginning of field work is of great practical importance. In some regions this is a main factor governing the growth and development of agricultural crops. However, the direct evaluation of water content in soil from microwave emission measurements is impossible, since, as has been stated above, it is impossible to reproduce the moisture profile in the 1-m layer of the soil. Preliminary calculations have lead us to a conclusion that for all real moistures of the soil, the upper layer contributes mostly to radiobrightness temperature.

The problem considered can be solved by obtaining correlations between the moistures of surface layers of different thicknesses evaluated from microwave emission at several wavelengths, and the humidity profile in the layer of interest.

In this connection, we consider the main agrohydrological characteristics of the soil. The main parameter determining the water content in soil is the soil moisture, i.e., the percentage of the water content to the weight of the dry soil (weight moisture) or to the volume of the dry soil (volume moisture). These two parameters are related as follows:

$$\omega_v = \omega_p \cdot D \quad (11)$$

where ω_v is the volume moisture in percent; ω_p is the weight moisture in percent; D is the volume weight of the soil in g/cm^3 .

The volume weight of the soil is the weight of the unit volume of the absolutely dry soil of natural structure, in the undisturbed state. If the subsoil waters' level is at a sufficient depth, then, as the soil moistens, all the pores become filled with water. The amount of water in the saturated soil is called "total water-capacity". It is expressed in percentage of the dry-soil weight or in millimeters of precipitated water. The portion of the water filling all the pores of the soil, will seep deep into it, because its weight exceeds the force of the water-soil cohesion.

The remaining water, the weight of which is balanced by the force of cohesion with soil, is called "suspended water". The amount of suspended water is called the minimum field water-content. This is expressed in percentage of the dry-soil weight or in millimeters of precipitated water. The absolute amount of water in soil, or the total water content, is expressed in millimeters and determined from the following relationship:

$$Q_t = 0,1 \cdot \omega_p \cdot D \cdot Z \quad (12)$$

However, not all the water in soil can be used by growing plants. At some values of the soil moisture, other than zero, the plants fade. This remaining humidity is called fade coefficient and expressed in volume or weight percentage. According to this, the portion of the total water amount which can be absorbed by plants is called the productive-water content in soil and determined from the formula:

$$Q_p = 0,1 (\omega_p - q) D \cdot Z \quad (13)$$

The values of the volume weight of soil (D) and of the fade coefficient (q) for each type of the soil are measured periodically and reported in the guides on agrohydrological properties of soil. The amount of productive-water content in the 1-m layer is usually of interest for agrometeorology.

It was said above, however, that in microwave measurements, only the moisture of the surface layer can be determined, which forms the main portion of emission. Thus, to solve this problem, it is necessary to determine correlation between the humidity of the surface layer and humidity profile in the 1-m layer. When the level of the subsoil waters is deep enough (deeper than 1-m), correlation should exist between the profile of the minimum field water-content and that of humidity.

The analysis of real humidity profiles obtained in spring from the agrometeorological stations of the Northern Kazakhstan, confirmed the assumption that the depth-dependence of humidity corresponds to a mean profile of the minimum field water-content for a given type of the soil. This is true only for equilibrium conditions, when the surface layer of the soil is not moistened by irrigation or precipitation. In any case, however, the humidity lapse rate corresponds at a sufficient depth to the profile of the minimum field water-content. Only the surface layer lapse rate is subjected to substantial variations.

Figure 6 shows humidity profiles obtained at one of the meteorological stations of Kazakhstan in April, 1975 to illustrate the agreement between the lapse rate of the real humidity profile and that of the minimum field water-content profile. The straight line corresponds to the mean profile of the minimum field water-content for black soil, and the dotted line is the supplementary profiles of the minimum field water-content reproduced from humidity at a depth of 5 cm.

To determine the water content in the 1-m layer, we use a two-parameter model of humidity profile based on correlation between humidity profile and that of the minimum field water-content. One parameter is the humidity of the 5-10 m layer determined from radiometric measurements at $\lambda = 18$ cm, IR measurements and the plot of emissivity vs. humidity. This made it possible to eliminate the effect of the highly variable undersurface layer. The other parameter is the lapse rate of the minimum field water-content profile.

The water content in the 1-m layer was calculated from real soil-humidity profiles obtained during the aircraft experiment. Calculations were made using our two-parameter model. The results have shown that the mean relative error is 13 percent, and the maximum error does not exceed 35 percent. Such an accuracy is quite satisfactory to obtain the operational data on water-content in soil.

Thus, the information about the surface layer moisture and type of the soil is needed for remote sensing of water content over large area.

The above-stated theoretical hypotheses were experimentally checked up during the complex expedition carried out to develop technique and measure the productive water-content in soil. The expedition was carried out in the Northern Kazakhstan before a seed-time, in the spring of 1975. Measurements of microwave emission from the underlying surface were taken from board the MGO IL-18 flying laboratory. The radiometric data ($\lambda = 1.6$ cm and 18 cm) and those of the IR radiometer (8-12 μ m) were then processed.

The results of microwave emission measurements were used to evaluate the surface humidity ($\lambda = 1.6$ cm) and the humidity in the 5-10 cm layer. Ground measurements of the soil moisture, water content and temperature profiles were taken at a network of the Hydrometeorological Service. Besides, the scientists of the Department of Soil Science of the Leningrad State University measured temperature, moisture and volume weight in the 1-m layers of different types of the soil in this region. Aircraft measurements were made during three days of each ten days of April, which enabled one to cover the whole investigated area of 150000 km².

During each survey, the aircraft measurements were made in such a way that the uniform covering of the whole area could be obtained.

During the expedition, the aircraft microwave data were processed by express-technique, and the operational information about water content in soil was obtained for practical application of the data on productive water content in soil. After the expedition, the data on radiobrightness temperature obtained at $\lambda = 18$ cm were processed and the productive water content in soil was evaluated using the two-parameter model.

Having compared the observed data with calculated ones, we found out a systematic discrepancy between the data of remote sensing and those of measurement. The analysis of all the possible sources of discrepancy showed that the values of soil emissivities used to interpret the results were much lower than the experimental values. This testifies the fact that the dielectrical constants for sand and clay reported in Ref. [17] and used in calculations of emissivity are somewhat higher as compared to real ones.

The comparison between the emission coefficients obtained from aircraft measurements and the real soil moisture in the 5-10 cm layer obtained from

ground observations, has made it possible to specify the dependence of emissivity on soil moisture at $\lambda = 18$ cm. To illustrate the above-said Figure 7 gives emissivity vs. moisture calculated from the data of Ref. [17] (curve 1), and obtained aircraft measurements (curve 2). Note, that some authors [16,18] also report higher values of emissivity of real soil. Figure 7 shows experimental results cited from Ref. [16] (curve 3).

Figure 8 shows the productive water content in the 1-m layer in millimeters of precipitated water for the second ten days of April calculated from specified dielectrical constants. Examining the scheme, we can see a good agreement of the water-content values obtained by remote sensing, with the ground-truth measurements (the ground-truth data are given in Figure 8 in frame), especially if we take into account the difficulties arising in comparison of local ground-truth measurements with those averaged over large areas.

When analyzing the results of interpreting the aircraft microwave data, we should point out that such a parameter of the soil as the productive water content, varies significantly even at one geographical point. This is associated with wide variations of the fade coefficients in Equation (13). The difference between relative soil moisture and fade coefficient put in brackets is the difference between close values. The fade coefficient's variations lead, therefore, to considerable variations in the productive water content. Apparently, it is expedient to use not the productive water content but the total water content in the 1-m layer to characterize the spatial distribution of soil moisture, taking into account the resolution of the technique.

To calculate the productive water content, we use the averaged values of agrohydrological parameters of the soil obtained for the prevailing type of the soil on each site of the area under investigation.

Naturally, this may lead to appreciable discrepancy between the results of aircraft remote sensing and ground observations due to considerable variability of agrohydrological characteristics which depend heavily both on the type of soil and on the agro-background. Therefore, for practical use of remote sensing in determination of the water content in soil, special investigations should be undertaken to develop technique for obtaining the agrohydrological constants of the soil averaged over large territories.

To spatially averaged results of measurements also affect the accuracy of water-content remote sensing. The inhomogeneity of the underlying surface, and, in the first place, the presence of water reservoirs and the sites covered with forest and bushes, may lead to overestimation of water content in the first case and to underestimation in the second.

The analysis of the experimental data has shown that the technique suggested can be successfully applied to determination of soil water-content over large areas before a seed-time for spring crops or for fallow ground without vegetation. It is necessary also to further develop measuring and processing techniques, taking account of spatial inhomogeneities of agro-meteorological constants and applicable in the case where the ground is covered with vegetation.

Apparently, it is expedient to increase a maximum wavelength which will make it possible to obtain more reliable data on the surface layer moisture, for high humidities of the soil, in particular.

Surface	Brief description	Wave-length (cm)	Air temp. °C	Σ
Laboratory measurements				
Soil	Thickness: 20cm			
	Moisture (w):			
	$w = 6.4\%$	3.2	21	0.947
	$w = 19\%$	3.2	20	0.919
	$w_{\text{surf.}} = 21\%$	3.2	23	0.923
	$w_{h=20\text{cm}} = 20.1\%$ $w_{\text{surf.}} = 34.6\%$ $w_{h=20\text{cm}} = 17.5\%$	3.2	22.5	0.668
Soil	$t_{\text{soil}} = -0.4^{\circ}\text{C}$			
	$w = 13.9\%$	3.2	1.2	0.923
Thaw soil	$t_{\text{soil}} = +0.4^{\circ}\text{C}$			
	$w = 14\%$	3.2	0	0.892
Peat	$w = 114\%$	3.2	18	0.943
	$w = 159\%$	3.2	15	0.918
Clay	$w = 9\%$	3.2	15	0.902
Ground measurements				
Soil covered with snow	Snow layer = 20-30cm	3.2	1.2	0.956
	Density = 0.408 g/cm ³			
Frozen soil	Frozen layer=11-12cm			
	$w_{\text{surf.}} = 45.6\%$	3.2	0.4	0.941
	Grass cover			
	Frozen layer=6cm	3.2	0.4	0.927
	$w_{\text{surf.}} = 32.5\%$			

TABLE 1

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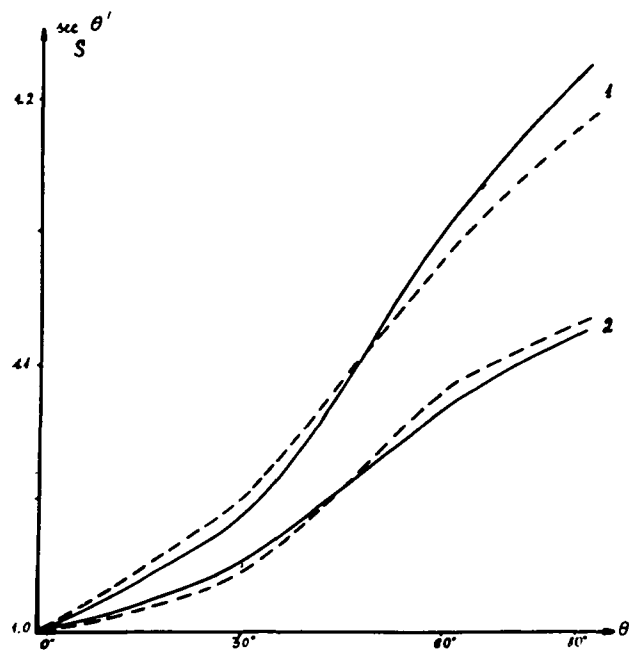


Fig. 1 Angular dependences of the functions $S(\theta)$ (-----) and $\sec \theta'$ (——) for $n = 1.76$ $\chi = 0.29$ (1)
 $n = 2.28$ $\chi = 0.44$ (2)

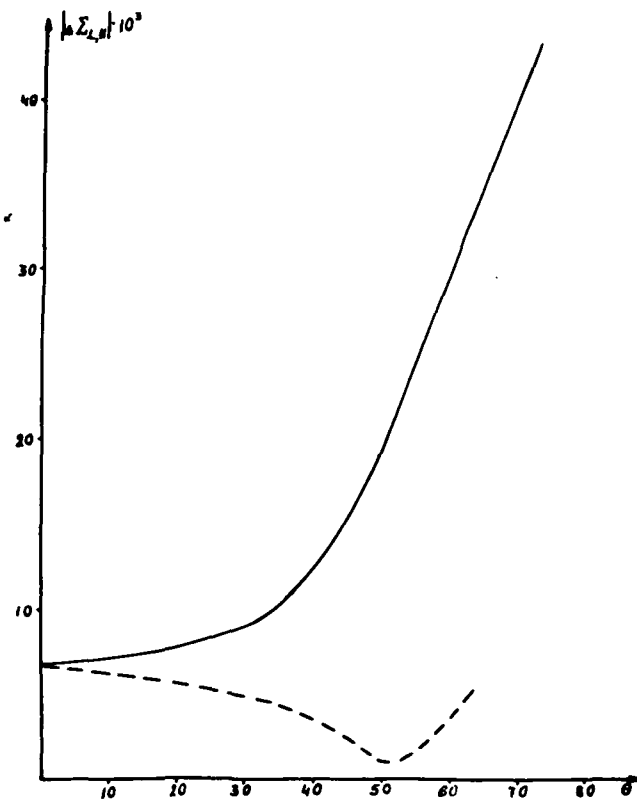


Fig. 2 Angular dependence of emissivity variations due to soil inhomogeneity at $\lambda = 60\text{cm}$, for the boundary value of dielectric constant, $\epsilon_0 = 1.7$ and dielectric permeability gradient, 10 m^{-1} .

———— horizontal polarization
 ----- vertical polarization

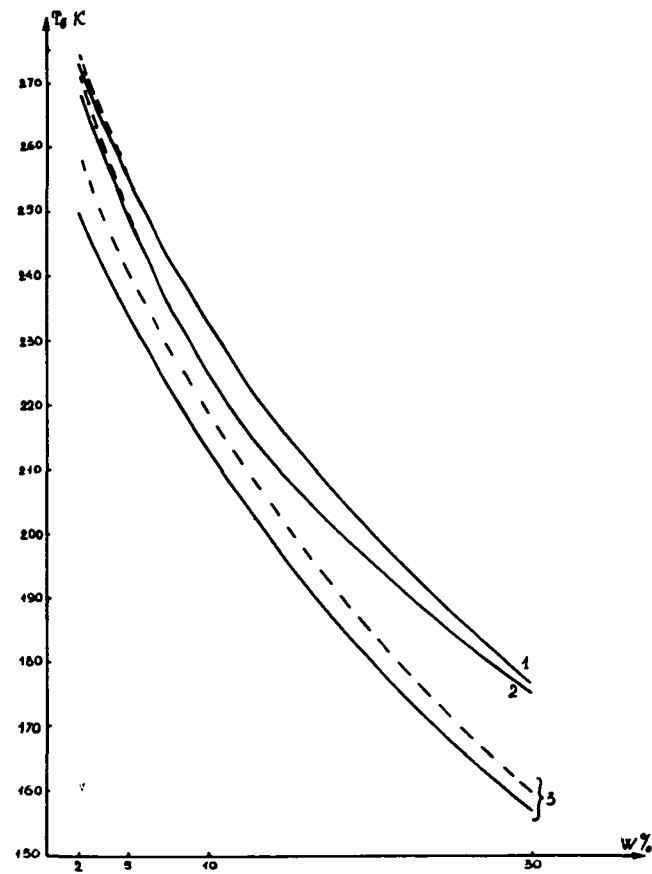


Fig. 3 Radiobrightness temperatures of the soil, T_{br} , with positive (-----) and negative (——) temperature lapse rate vs. humidity, w , at $\lambda = 0.8$ cm (1), 2 cm (2), and 18 cm (3).

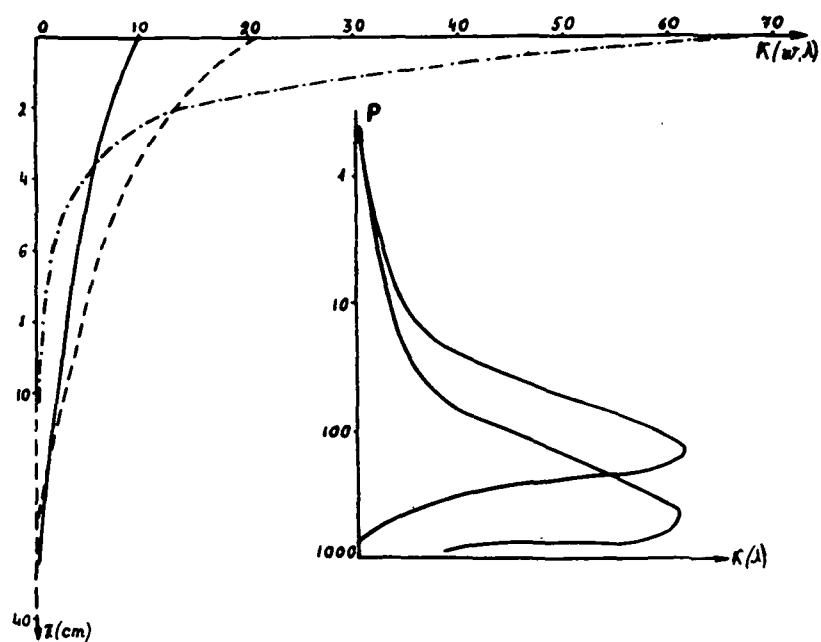


Fig. 4 Comparison between the kernels of the soil's temperature profile reconstruction problem (a) at different wavelengths, λ , for different soil moistures, w , and atmosphere humidities (b).

————	$\lambda = 10\text{cm}$	$w = 3\%$
-----	$\lambda = 10\text{cm}$	$w = 6\%$
-.-.-.-.	$\lambda = 3.3\text{cm}$	$w = 3\%$

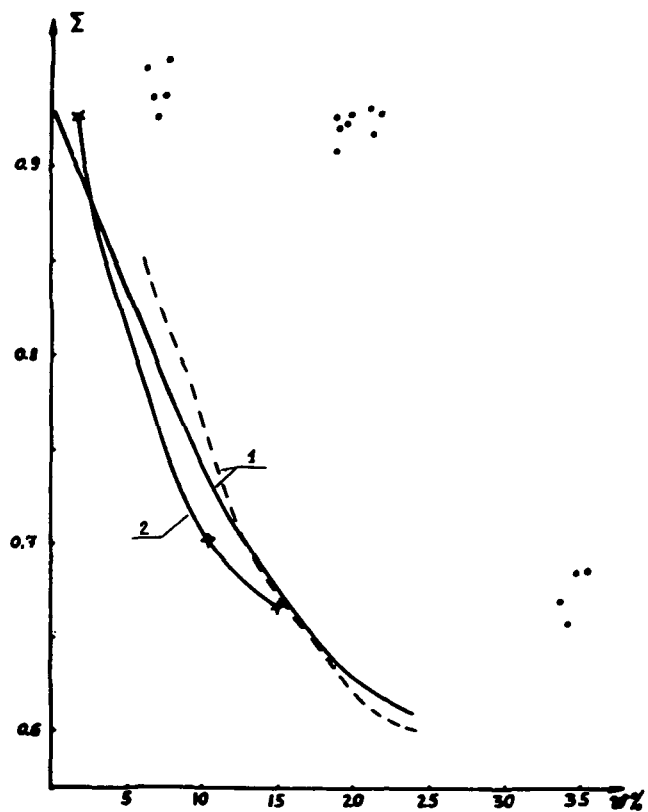


Fig. 5 Emissivity, Σ , vs. soil moisture, $w\%$.

1 - calculations from the data of Ref. [17_7]

———— sand

----- clay

2 - measurement data - river sand

The dots indicate sandy loam.

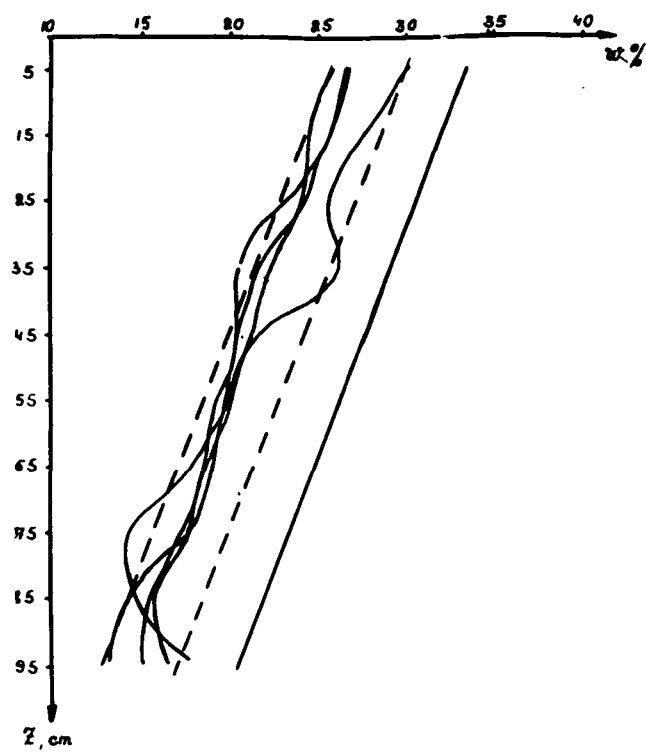


Fig. 6 Moisture profiles for black soil in April, 1975.

- mean profile of the minimum field
water content for black soil;
- supplementary profiles of the minimum
field water content reconstructed from
moisture at a depth of 5 cm.

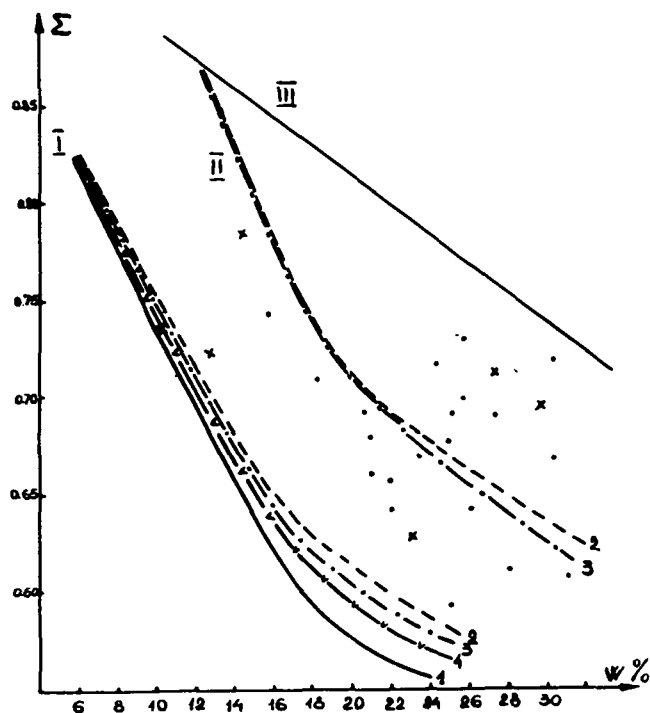


Fig. 7 Emissivities, Σ , of clay (1), black soil (2), light loam (3), and sand (4) vs. moisture, w , at $\lambda = 18\text{cm}$.

- I - calculations from the data of Ref. [17];
- II - from aircraft measurements (dots are experimental data) ;
- III - experimental data from Ref. [16].

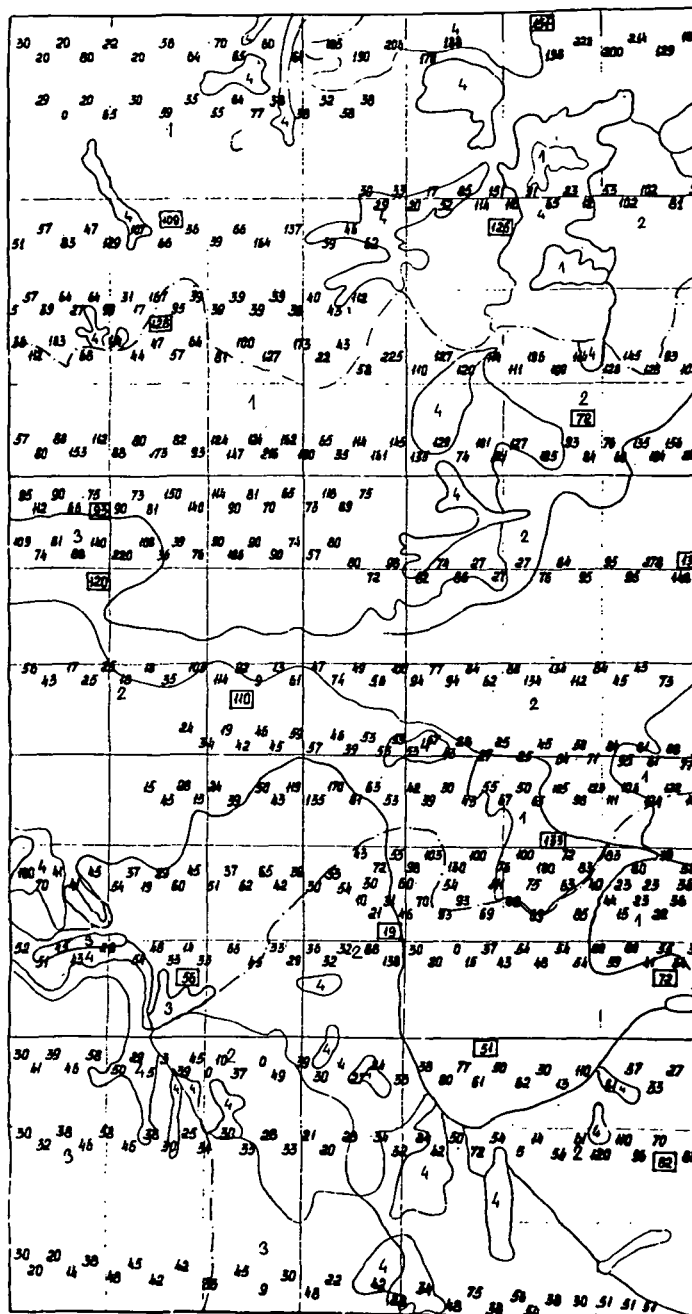


Fig. 8 Map of productive water content in soil (in mm) for
15-16 April, 1975.

1. Black Soils.
2. Dark chestnut soils.
3. Kight-chestnut soils.
4. Saline soils.

REPORT ON COMMERCIAL EXHIBITS

Twelve companies participated in the commercial exhibits section of this year's symposium. The following is a report on their activities:

THE HUGHES AIRCRAFT COMPANY, Space and Communications Group, El Segundo, CA

The Hughes Aircraft Company displayed the Hughes-built Multispectral Scanner (MSS) and a new remote sensor to be built by Hughes called Thematic Mapper was featured with graphics and scale models.

Although MSS has achieved spectacular success in carrying out the Earth Resources Survey mission, NASA and the user community together have set new, even more far-reaching goals for the future, requiring increased instrumental capability. To satisfy these requirements, a new remote sensor called Thematic Mapper has been designed.

Thematic Mapper will become the third generation in a family of precision multispectral instruments for earth resources studies from low-altitude satellites. The first generation - MSS-1 and MSS-2 now in orbit - has four spectral bands covering the visible and near-infrared regions. The second generation five-band MSS soon to be launched onboard LANDSAT C is adding thermal imaging to this capability. The new Thematic Mapper will be carried on LANDSAT D, scheduled for service during the 1980's.

Major performance improvements over the MSS were shown using photographs of the Washington, D.C. area simulated to compare MSS and Thematic Mapper resolution. The photos showed geometric resolution of Thematic Mapper to 30 meters - 2.5 times better than the 80 meters currently obtainable from MSS.

SOCIÉTÉ EUROPÉENNE DE PROPULSION, Tour Nobel, Cedex No. 3, 92080 Paris La Defense, France

Société Européenne de Propulsion showed a model of their VIZIR image display unit. The VIZIR unit was devised under contract to the French National Meteorological Organization and managed by the Lannion Space Meteorological Research Centre (Lannion-C.E.M.S.).

The VIZIR display unit, associated with a receiving station of the data issued from a satellite, allows supplying very accurate images of the observations on orbit. These images feature, in particular, high reproduction and resolution quality.

S.E.P. also distributed literature pertaining to their many other remote sensing activities.

THE EASTMAN KODAK COMPANY, Aerial Products, 343 State Street, Rochester, NY

The Eastman Kodak Company display featured four examples of remotely sensed imagery. The first print was made from a low-altitude (5,000 ft) aerial photograph of Letchworth State Park, New York, on KODAK AEROCHROME Infrared Film 2443 (ESTAR Base). The second example was made from a high-altitude (70,000 ft) photograph of Washington, D.C., also on 2443. The third print was made from a SKYLAB 4 photograph of Yuma, Arizona, taken with KODAK High Definition AEROCHROME Infrared Film SO-127 (ESTAR Base). The fourth image was a LANDSAT composite of the Finger Lakes region of New York State which had been reproduced in false color format by EROS Data Center using Bands 4, 5 and 7. These four types of imagery exemplify the results that can be obtained using different remote sensing techniques and regimens. The remainder of the booth was devoted to new and/or current Kodak Publications concerning aerial photography and remote sensing. Attendees were encouraged to complete information/request forms in order to receive a complimentary copy of any Kodak Publication(s) of interest.

DAMES & MOORE, 6 Commerce Drive, Cranford, NJ

Dames & Moore displayed their capabilities in computer analysis of digital multispectral data. The equipment used consisted of a portable computer terminal that accessed a remotely-located computer and printed out examples of land use maps and exploration geological maps, all of which were from actual Dames & Moore projects. A series of products were generated to show the general methodology used in determining spectral signatures. Both supervised and unsupervised methods were demonstrated. Examples of other remote sensing applications by Dames & Moore were also shown.

GEOSPECTRA CORPORATION, 320 N. Main, Suite 301, Ann Arbor, MI

GeoSpectra Corporation offered examples of their complete services in satellite geological remote sensing, ranging from the processing of Landsat computer tapes with their unique software system to the interpretation and field application of the resulting image products. The company has served both large and small mineral and petroleum companies and has participated in wide-area exploration projects (as large as 600,000 square kilometers) which have yielded new mineral deposits. Although the company's principal interest has been in mineral and hydrocarbon exploration, it has successfully tackled other remote sensing problems as well, such as rangeland management and coastal zone mapping.

AMERICAN GEOGRAPHIC, INC., 3109 Thompson Road, Fenton, MI

American Geographic, Inc. exhibited a display of lithographed reproductions of maps derived from remotely sensed data and reproductions of land-use maps in the four color processes.

OPTRONICS INTERNATIONAL, INC., 7 Stuart Road, Chelmsford, MA

Optronics International, Inc., a manufacturer of scanning micro-densitometers and film writers, exhibited their latest product which writes directly on color film. Digital imagery such as that from Landsat or Viking Mars has historically been plotted using their Photowrite as three black and white film transparencies, each corresponding to one primary color and later superimposed onto color film. This process requires time and care. However, Optronics' new Colorwrite simplifies color image production because it can selectively expose each of the emulsion layers of color film with little or no operator interaction. Also shown were larger format graphics where 17" x 22" black and white transparencies can be scanned or plotted in less than seven minutes.

INSTRUMENTATION MARKETING CORPORATION, 820 S. Mariposa Street, Burbank, CA

Instrumentation Marketing Corporation displayed a new low-cost, easy to use combination for multispectral image acquisition and interpretation. This included: the hand-held MB-470 Camera which provides 4 separate images in the R, G, B and IR band on a single 70mm frame format. The composite image can be created on the AC-70 Additive Color Viewer. Also the new AC-90 Additive Color Viewer for 9.5 inch Multi-band imagery on Landsat scenes offers the capability to produce composite imagery using a high resolution optical system with extreme brightness. A unique motorized registration of X-Y axis was provided. The 4200-E Multicolor Data System is an analog system capable of video processing and classification of both multi-band and Landsat scenes.

PROSPACE, 129 Rue de l'Université, 75007 Paris, France

PROSPACE, an organization grouping 42 French firms and CNES (French Space Agency) presented the products and activities of its 10 members active in Earth Observation. Visitors had the opportunity of seeing what is being done in France in the fields of image taking, data processing and display technology.

PROSPACE also presented the Argos Franco-American operational system for collection of environmental data and location of drifting platform. The French firm E.M.D., selected by CNES (French Space Agency) to develop multipurpose platforms (buoys, ships, ground stations, etc.) compatible with the Argos system, displayed a prototype beacon.

SPATIAL DATA SYSTEMS, INC., Box 249, Goleta, CA

Spatial Data Systems, Inc. displayed its Model 830 Image Processing System for the analysis and enhancement of remote sensing film. The Model 830 is capable of digitizing Landsat multi-spectral film, IR scanner film, or false color infrared film using selected filters to separate the color layers. The heart of the Model 830 is their EyeCom Picture Digitizer and Display Terminal which uses the EyeCom Scanner to scan any film from 16mm up to 9 1/2" x 9 1/2", and to register the multispectral films under the camera so that any portion of the Landsat imagery may be scanned at any magnification and remain in precise registration from band to band. The software available with the Model 830 includes filtering techniques, contrast expansions, ratios between bands, various edge enhancement routines, and a feature classification routine. Information as to density or brightness of areas or points, as well as area measurement of various features, can be obtained and displayed. In addition to handling the films, the Landsat tapes may be read into the computer and the files for each of the bands handled in the same manner as the film separations. The Model 830 Image Processing System also includes a color output display so that up to 32 color may be displayed of the features selected from the multispectral images.

GENERAL ELECTRIC COMPANY, 5031 Herzel Place, Beltsville, MD

General Electric Company displayed some of their Image 100 Products which show color coded thematic data overlay and register to a base map at a scale of 1:250,000. It also contained quantitative information regarding each color coded theme in table format.

HUNTING SURVEYS AND CONSULTANTS, INC., 790 Madison Avenue, New York, NY

Hunting Surveys and Consultants, Inc. displayed the world wide remote sensing experience of the parent company in the United Kingdom. Hunting, with a graduate staff of over 100, provides a wide range of consultancy services in oil and mineral exploration, land and water resource studies and topographic, hydrographic and airborne surveys.

The Company makes extensive use of remote sensing imagery projects in over 30 countries and has used LANDSAT, SKYLAB, SLAR, THERMAL IR and a variety of photography.

The Company displayed an example of LANDSAT interpretation from Afghanistan. In 1976 Hunting assisted regional planning in N.E. Afghanistan, furnishing a rapid appraisal of the entire Konar River and mapping of land resources at 1/250,000. Complete coverage was afforded by two enlarged False Color Composites of LANDSAT imagery. These images provided a mapping base of high interpretive quality and enabled land resource mapping of inaccessible mountainous terrain at a fraction of the cost of more conventional aerial photographic methods. The exhibit presented an account of the Afghanistan survey (False Color Composite, frames in Bands 4, 5 and 7, and overlay exemplifying land resource mapping).

Hunting is currently engaged upon mapping the vegetation of the whole of Nigeria from radar imagery and training Nigerians in remote sensing technology. Activities in digital remote sensing analysis are supported by the specialized services of the Image Analysis Group, UKAEA, Harwell, United Kingdom.

REPORT ON PARTICIPANT QUESTIONNAIRE RESPONSE

Organization of this series of symposia regularly involves an attempt to accommodate the broadest possible range of participant interest, background, and expertise; to include material of importance to the remote sensing technologist, as well as the user of this technology; and to provide a useful forum for the scientific, commercial, governmental, and academic communities.

To assist in ensuring that, to the extent possible, these goals are met; and that future meetings are responsive to the changing needs of this maturing technology, as well as those of the participating remote sensing community, a questionnaire was distributed to the attendees of the Eleventh International Symposium on Remote Sensing of Environment (see next page for a copy of the questionnaire).

One hundred ninety questionnaires were returned, 95 of which were from poster session authors.

82.1% of the sampling felt the Industrial Exhibit Section added substantially to the overall program and should be continued; 12.6% felt it was relatively unimportant to their interests or to the meeting's success; and 5.3% made no comment on the exhibits.

Of the symposium participants who answered the questionnaire, 85.8% felt the poster session provided greater freedom and in-depth discussion than traditional modes of presentation; 8.4% felt it (poster session) less desirable than traditional presentations, while 5.8% were undecided or had no comment. 84.2% of the respondents felt the poster sessions should be continued at future symposia; 4.7% felt they should not; and 11.1% had no comment. As for the length of time of each poster session, 8.4% felt they were too short; 3.3% too long; 77.9% of the respondents felt the time period was of satisfactory duration and 10.4% had no comment.

Of the poster session authors, 86.3% of those answering questionnaires responded favorably, to the poster session format; 8.4% negatively; while 5.3% were either undecided or gave no comment. 85.3% felt the poster session format should be continued; while 5.3% felt they should not; 9.4% had no comment. 6.3% of the authors felt the poster sessions were too short; 1.1% too long; 75.8% satisfactory; and 16.8% had no comment.

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questionnaire distributed to 11th symposium attendees:

I. ALL PARTICIPANTS

- (1) Exhibits. Recent symposia have included a limited commercial/industrial exhibit section, aimed at evaluating the relative importance of this element of information exchange. This aspect of the symposia:

- ☐ adds substantially to the overall program and should be continued
- ☐ is relatively unimportant to meeting success and to my interests or needs

Comments - Please feel free to write comments on back

- (2) Poster Sessions. The poster-session format inherently trades quantity of presentations to which the participant is exposed for quality of in-depth discussion and individual selection. In terms of effective communication and information exchange the poster-session format:

- ☐ provided greater freedom of selection and in-depth discussion than traditional modes of presentation
- ☐ is less desirable than traditional presentation
- ☐ should; ☐ should not be continued at future symposia

Individual poster sessions in the current symposium were:

- ☐ too short; ☐ too long; ☐ satisfactory

Comments - Please feel free to write comments on back

II. PARTICIPANTS MAKING POSTER PRESENTATIONS

The poster session format utilized at the current meeting:

- ☐ allowed for more effective communication and presentation of ideas, results, than traditional modes of presentation
- ☐ resulted in a more (or less ☐) rewarding presentation and discussion with interested participants
- ☐ is less desirable than traditional presentation
comment: _____
- ☐ should; ☐ should not be continued at future symposia

Individual poster sessions in the current symposium were:

- ☐ too short; ☐ too long; ☐ satisfactory

Comments - please feel free to write comments on back

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